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METHODS OF COLLECTING AND ANALYSING SIZE AND AGE DATA FOR FISH STOCK ASSESSMENT

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
ROME, October 1981

PREPARATION OF THIS DOCUMENT

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ABSTRACT

Starting with a brief introduction on the uses of size and age data in fisheries investigations, the circular first discusses the various considerations connected with measurement of fish size, namely, choices of length dimensions to be measured, unit of measurements to be chosen, methods of measuring whole, damaged and processed (e.g., headless) fish, and of recording and reporting such data and the types of forms used. It is followed by a discussion on the sampling programme for the estimation of size composition of commercial landings together with a brief description of sampling the natural fish population in the sea. The discussion covers criteria of stratification in designing sample surveys for size composition, sampling methods and estimation procedures with numberical illustrations. The method of obtaining length-weight relation in fish is then described for use in cases where weight sampling is done and size composition estimated by employing the length-weight relation.

Next, indirect and direct methods of age determination of fish are dealt with. As scales and otoliths are used for direct ageing of fish, methods for their collection, storing and mounting, and of preparation and viewing and reading them are described in some detail. Possible sources of errors in reading scales and otoliths are also mentioned. This is followed by a description of methods of back calculation of sizes of fish at earlier preceding ages from scale and otolith readings. Age-length key forms the next topic illustrating its use in obtaining estimates of age composition from those length composition of commercial landings. Finally, the uses of age and age composition data in fitting growth curves and estimating mortality rates are briefly described with numerical examples.

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1. INTRODUCTION

From the time they are spawned, the individual fish in a brood increase both in size and in weight and at the same time they are reduced in number due to natural causes of death or fishing if the population is exploited. The total weight of the brood, at any given time or age, is determined by the resultant of the rates of growth and mortality. In fact, most analytical models of fish population dynamics depend largely on a knowledge of growth and mortality rates. It is obvious that for estimating growth rate (by size or by weight), it is desirable to determine the age of individual fish and that for estimating mortality rate, some idea of the age composition of catches is desirable. Direct determination of the age of individual fish from marks on scales and in other skeletal structures is time consuming, and sometimes almost impossible as in the case of many tropical fishes. Indirect methods of age determination are possible from data on frequency distribution of length measurements and are frequently resorted to, in addition to other methods of direct age determination in case of fishes of temperate waters. For fish of tropical waters where annual or seasonal growth checks in skeletal structures are of uncertain interpretation, this latter constitutes probably the most feasible method of age determination.

Since it is rather easy to measure the size of fish quickly and it does not require costly and elaborate equipment and since, apart from their uses in the estimation of growth and mortality rates, fishery scientists often use size data for various other purposes, the collection of size frequency of fish constitutes a very important part of fisheries investigations all over the world. In fact, since in making assessments we are interested in the interactions of growth and mortality and their effects on numbers and sizes of fish, rather than in growth and mortality rates per se, it is possible to make analyses directly from length composition data.

In this circular we will first briefly enumerate the various uses of size data in fisheries investigations along with discussions on the problems connected with the measurement of the size of the fish and then we will deal with the methods of age determination and estimation of age composition of commercial landings. Finally, we will illustrate the uses of age and age composition data.

2. USES OF SIZE AND SIZE COMPOSITION DATA

There are various uses of length and length composition data. First, from an analysis of length-frequency data, it is possible to determine the ages of fish of various lengths and therefore to estimate age composition of commercial catches from corresponding size composition data. This enables us to estimate growth and mortality rates and also in identification of year classes. Sometimes estimation of all these is possible directly from length data (Pauly, 1980). Assessment of the effects of changes in fishing practice, e.g., of changes in mesh size, or in total fishing effort can also be made from length data (Gulland, 1961; Jones, 1981).

If there is a long time series of length-frequency data, a close scrutiny of such data may reveal many features of a fishery. It is well known that the number of the incoming year class (i.e., number of recruits to a fishery) varies a great deal from year to year. Such variations in the number of recruit class are generally due to effects of random environmental factors operating on the progeny of a year class before it enters the fishery. But sometimes, the variation in the recruit class may be directly related to the changes in the spawning stock. A prolonged and continuous fall in the number in the incoming year class may indicate that a stock is no longer capable of regenerating itself and is suffering from a recruitment failure. In fact, a close scrutiny of the recruit class may sometimes offer a rough basis for prediction of future fishery prospects. In general, if a fishery exploits several age groups, moderate variations in recruitment will not very much affect the yields for future years (provided fishery effort remains constant), but if a fishery depends on only one or two age groups including the recruit class, variation in recruitment will almost immediately affect the future yields.

There are still other uses for length data. Length is usually closely related to other characteristics such as weight, age, maturity, etc. Usually, length data are available for samples of fish taken from many localities but determinations of age are made on a sub-sample. The age composition of the fish in the whole sample is derived by constructing an age-length-key from the sub-sample of fish.

The same principle is applied in obtaining a length-weight relationship based on measurements of fish in a sub-sample. This relationship or key is used to construct length distribution of catches into weight. The preceding description of the uses of the length data shows how important it is to start collecting this information. All that is needed is a measuring board, a pencil, a notebook in which to record the measurements and a sampling plan spelling out the species for which length data are required and how many fish are to be measured and how they are to be selected. It is also necessary to clearly spell out the actual linear dimension that is being measured as length and how this is being measured and in what units these measurements are being recorded. All these form the topics for the subsequent sections.

3. MEASUREMENT OF FISH AND SHELLFISH

Measuring lengths of whole or parts of fish is probably a universal practice in fisheries research. As several measures of length dimensions are in common use, they are briefly defined below separately for fish and shellfish.

3.1 Measurement of Bony Fishes

There are three main length measures for fish, namely:

(i) Standard length
(ii) Total length
(iii) Fork length

These measures are illustrated in Figure 1.

Standard length is properly measured from the premaxillary symphysis (i.e., tip of upper jaw) to the tip of the hypural bone (urostyle), but in many fisheries studies it is also measured from the dentary symphysis (i.e., tip of lower jaw) and instead of to the tip of the hypural bone, it is measured in practice, to some external features more or less corresponding to the latter point; this would vary from one species to another but examples are the last scale, or point of silvering, to the edge of skin pigment (determined by scraping away the posterior scales), to the lip of the fleshy peduncle or to the keel. Standard length is rarely used in fisheries studies except by taxonomists. It is difficult to record accurately while working at speed and it has little to recommend its use in the field.

Total length is measured from the tip of either upper or lower jaw to the tip of the longest caudal fin rays. The measurement may be made in several possible ways. It may be made to the tip of the dorsal lobe, or to the ventral lobe, or to the longer of the two or some average of them both (such as to the mid-point of a line joining the two tips or to the point where such a line crosses the median longitudinal axis). The tail fin may be in the normal extended position to give total length, or the tips of one or both caudal lobes may be drawn to the longitudinal axis to give extreme total length. Sometimes, total length measurements are made with the caudal lobes partially drawn together so that their outer edges are parallel to each other and to the axis. Damage to the tip of the tail, especially in frozen fish may make it difficult to measure total length.

Fork length is also measured from the tip of either upper or lower jaw to the cartilaginous tip of the shortest, or median, caudal fin ray. This may also be difficult to measure if the tail is split and the fork is not well defined.

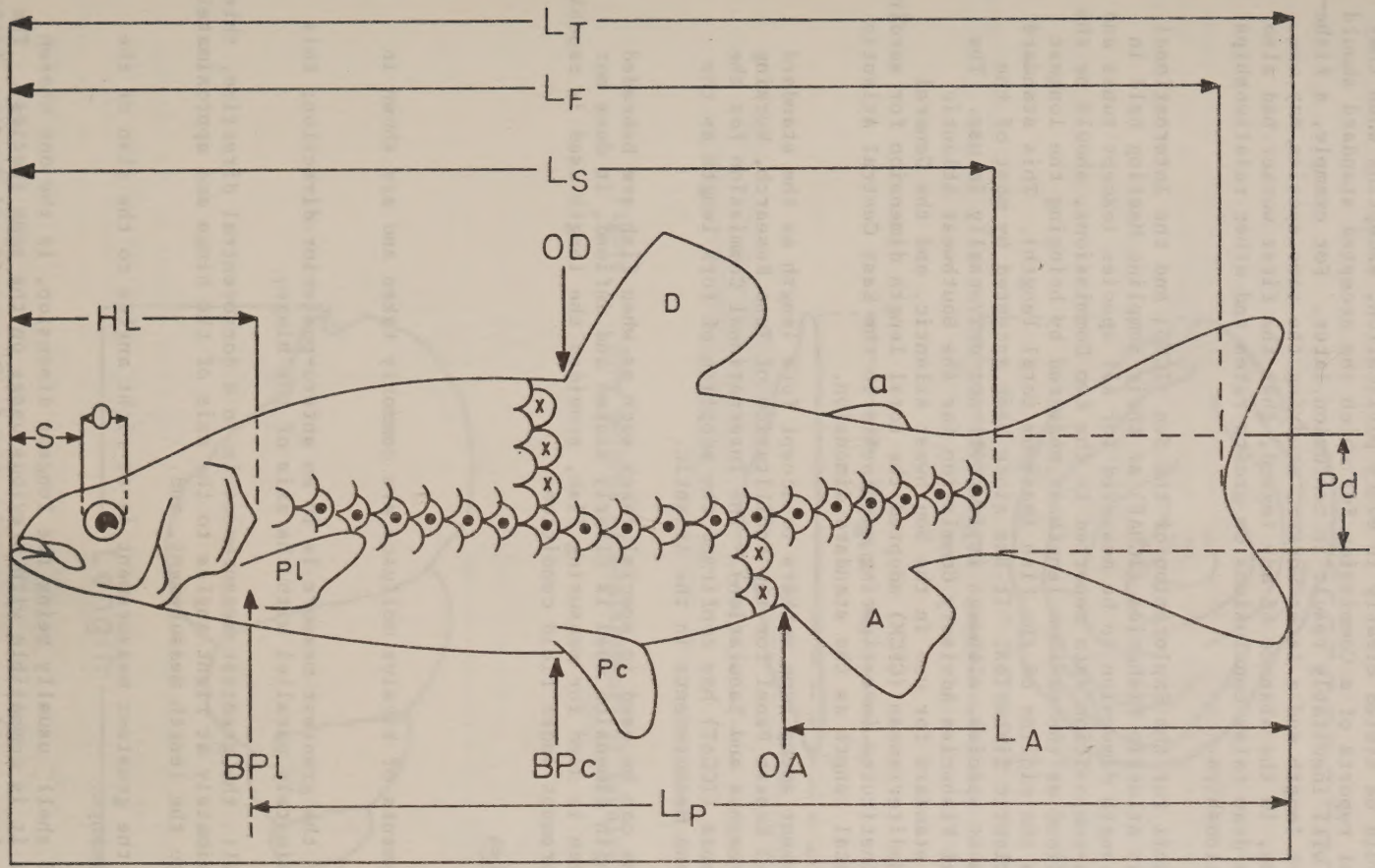


Figure 1 Some standard body dimensions of bony fish

A	Anal fin
a	Adipose fin
BPc	Base pectoral fin
BPl	Base pelvic fin
D	Dorsal fin
HL	Head length
LA	Length from base of anal fin
O	Diameter of orbit
OA	Origin anal fin
OD	Origin dorsal fin
L_F	Mid-caudal length
L_S	Standard length to peduncle
L_T	Total length
L_p	Length from base of pectoral
Pd	Caudal peduncle
S	Snout length

It is therefore clear that precise instructions must be given as to the dimension to be measured and also the method of measuring. It is important to remember that whichever measurement is used, it should be stated clearly in every publication, excepting when they are published in statistical reports of a Commission for which the accepted standard should be used. Failure to do so will inevitably result in confusion later. For example, a fisheries worker may measure fork length and a later worker, studying the same species, may use total length. He may assume, in the absence of any legend, that the first worker had also used total length, and thus draw false conclusions on growth rates and other relationships such as length-weight relationships.

The International Council for the Exploration of the Sea (ICES) and the International Commission for the Northwest Atlantic Fisheries (ICNAF) at their Sampling Meeting held in 1965 recommended that the length dimension to be measured for all species (except tunas and salmonids) for which length-composition data reported to the two Commissions, should be the total length. This was defined as the maximum length as measured by bringing the longest lobe of the caudal fin into the midline of the fish (maximum total length). This standard covers most of the North Atlantic fisheries. It has since been accepted by most of the ICES member countries for most species, although it is still not universally in use. The 1968 Meeting of the Regional Fisheries Advisory Commission for the Southwest Atlantic (CARPAS) approved the same standard for use in the Southwest Atlantic, and the General Fisheries Council for the Mediterranean (GFCM) adopted the total length dimension for sardine. The West African Research Institutes investigating sardinella in the East Central Atlantic (CECAF) also adopted the total length as the standard dimension.

There is general agreement among tuna workers to accept fork length as the standard dimension (Report of the FAO Expert Panel for the Facilitation of Tuna Research, Working Party on Tuna Length Measurements and Tabulation). The International Commission for the Conservation of Atlantic Tunas (ICCAT) has confirmed the adoption of fork length as the standard measure for all tuna measurements in the Atlantic.

Other length dimensions can be used in special cases such as when fish are beheaded before landing. If the length dimension used is clearly stated and defined, it does not matter which length dimension is used for measuring fish, provided the length used is capable of quick and reliable measurement under field conditions.

3.2 Measurement of Shellfish

3.2.1 Molluscs

Three possible measurements of bivalve molluscs are commonly taken and are shown in Figure 2:

(a) Length of shell: the greatest measure is in an antero-posterior direction; this is usually approximately parallel with the axis of the hinge;

(b) Width of the shell: the greatest measurement is in a dorsoventral direction, this is usually approximately at right angles to the axis of the hinge and approximately at right angles to the length measurement, and

(c) Depth of shell: the greatest measurement is at right angles to the plan of the above two measurements.

In general "length of shell" usually being the longest dimension, is the one chosen for measurement (as long as it is compatible with previous usage on the same species). The measurements are made with either calipers or measuring boards (Loosanoff and Nomejko, 1949).

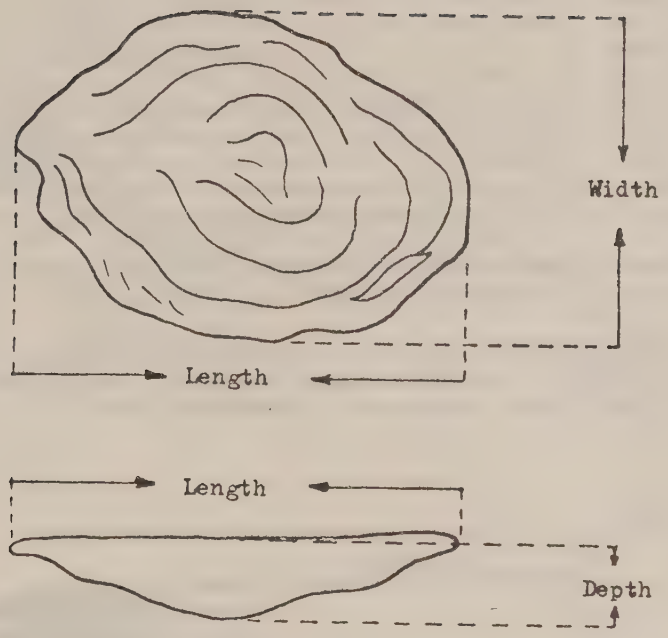


Figure 2 Some methods of measurements of bivalve molluscs

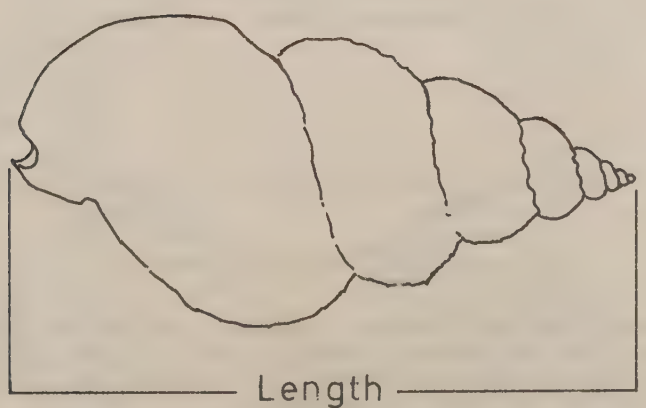


Figure 3 Standard method of measuring length of gastropod molluscs

It may be noted here that the usage of terminology of measurements often differs from true morphological conventions. In bivalve molluscan morphology the hinge is anatomically dorsal, and hence depth is correctly the dorsal-ventral measurement and is used as such in mussels and clams. For oysters and scallops, etc., which lie prone, the morphologically dorsal (hinge) position is on the side, and hence the (morphologically incorrect) reversal of terminologies depth and width is frequently found in the literature on shellfish. It is advisable: (a) to use the same description and terminology as previous workers to avoid confusion, and (b) to define what are meant by the terminologies width and depth, when these measurements are used. Similarly for scallops, the dorsoventral measurement is often described as the length. Once again, it is suggested to check and follow the existing convention for the species and clearly mention the measurement that is being made.

The standard measurement of gastropod molluscs is the maximum measurement from the tip of the whorl to the base of the shell (Figure 3) (Warren, 1958).

The standard measurement of cephalopods is the mantle length (Figure 4) although because of body plasticity, weight is a more accurate and less variable index of size and is often used as a standard measurement (Amaratunga and Durward, 1978).

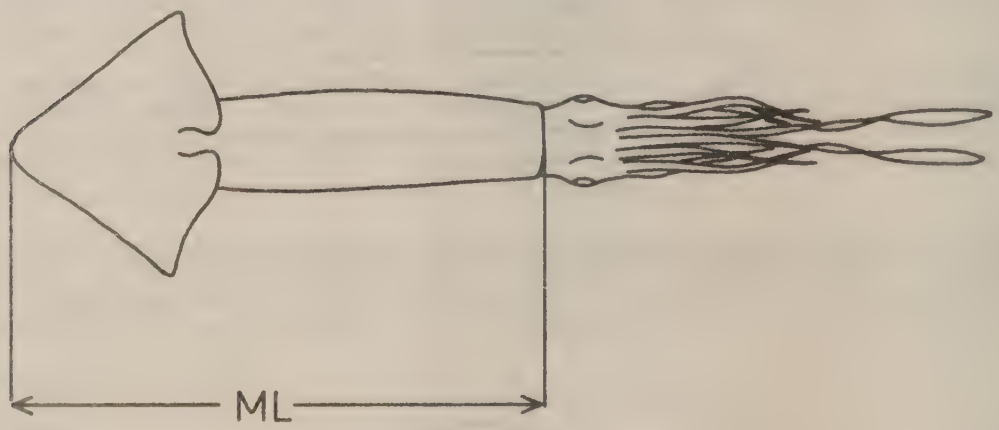


Figure 4 Standard measurement of mantle length (ML) of cephalopods

3.2.2 Crustacea

The standard measurement for lobsters, crawfish, shrimps and prawns is the minimum length of the carapace from the inside of the eye socket to the posterior margin of the carapace (Figure 5). In some cases (lobsters), the measurement is conveniently taken parallel to the midline and in others (some shrimps) it is from the eye socket to the centre of the dorsal margin of the carapace. (Cole and Mistakidis, 1953). It is important that existing conventions for the species in question be checked in the literature, since, for example, for some lobsters only tails are landed, and thus it would be convenient to use tail length or tail weights as standard measurement.

The standard measurement of crabs is the maximum distance across the width of the carapace (including the spines if present), at right angles to the median line (Figure 6). All measurements are made with calipers.

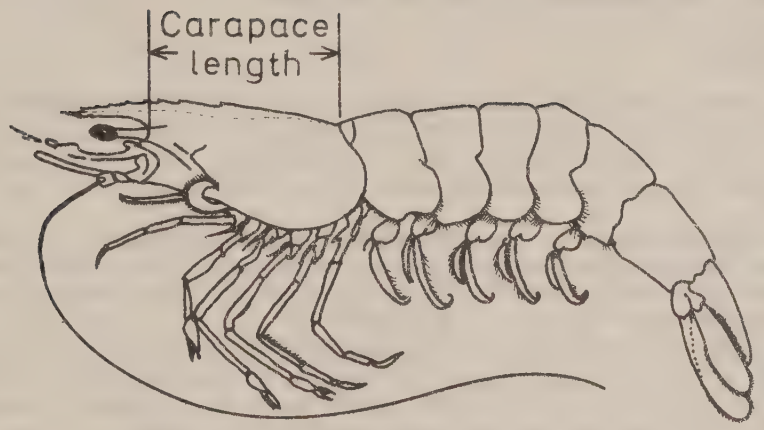


Figure 5 Standard method of measurement (carapace length) for decapod crustaceans

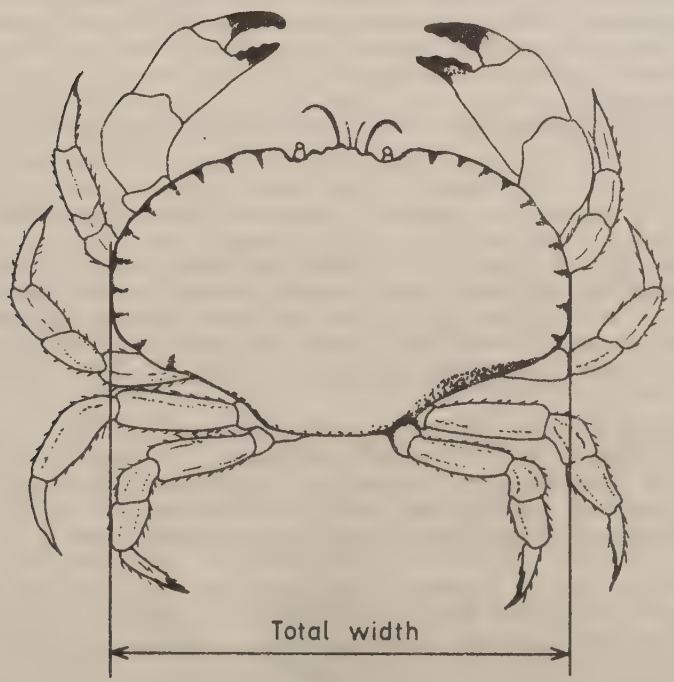


Figure 6 Standard method of measurement of total width of carapace in crabs

It should be noted that when using calipers, it is necessary to maintain the dimension that is being measured perpendicular to the inner edge of the caliper jaws, with the points of contact equidistant from the ends of the caliper jaws.

3.3 Unit of Measurement

The use of the metric system is recommended for all length measurements. The unit of measurement is usually 1 cm for species which grow larger than 30 cm, and 0.5 cm for species which do not reach 30 cm, or even smaller units if necessary. For very small species and for larval fish, it may be necessary to take the unit of measurement as 1 mm or smaller.

The method of reading length to the unit below has been agreed by the ICES/ICNAF Sampling Meeting 1965, the FAO Working Party on Tuna Length Measurements and Tabulation 1967, CARPAS 1968, the West African Sardinella Investigations 1967 and the GFCM sardine workers in 1963. According to this method, when the unit of measurement is 1 cm, lengths of all fishes greater than or equal to 26.0 cm but less than 27.0 cm are recorded as 26.0 cm. Similarly, when measuring is in units of 0.5 cm, lengths of all fish equal to or greater than 26.0 cm but less than 26.5 cm, are recorded as 26.0 cm and those equal to or greater than 26.5 cm but less than 27.0 cm are recorded as 26.5 cm. This convention is found to be more convenient in practice than measuring fish to the nearest unit, in which case the length, 26 cm, would mean all fish having length equal to or greater than 25.50 cm but less than 26.50 cm, when measuring to the nearest centimetre, and all fish having length equal to or greater than 25.75 cm but less than 26.25 cm, when measuring to the nearest 0.5 cm.

This practice of recording lengths to the unit below is similar to the procedure of preparing a frequency distribution table from a large set of measurements (e.g., length measurements). In the latter case, actual measurements are available and they are grouped in a number of desired equal intervals and the number falling in each interval is called the frequency of the class interval. In the procedure of recording lengths to the unit below, the class interval is determined by the unit of measurement chosen and instead of taking actual length measurements, they are grouped together by the procedure laid down for recording the measurement. But the most important distinction lies in the fact that in a statistical frequency table, the mid-point of the class interval is taken as the average value of all readings in the class interval and this is used for calculation of mean, standard deviation, etc. However, in the practice of recording lengths to the unit below, all readings in a class interval are given the measurement of the lowest value of the class interval; for example, in the method of recording lengths to the unit below, lengths of all fishes equal to or greater than 26.0 cm but less than 27.0 cm are recorded as 26.0 cm, when the unit of measurement is 1 cm, but in the statistical frequency table, the mid-point 26.5 cm would be taken as the average value of all such measurements. Hence, it is necessary to add half of the class interval, i.e., 0.5 cm in this case, to the mean length calculated from length measurements measured according to the unit below rule when fish are measured in units of 1 cm, and to add 0.25 cm to the mean length when fish are measured in units of 0.5 cm.

The unit of measurement may be in small units such as 0.5 cm or 1.00 cm, but it is often advantageous to present length data by larger groupings. The appropriate class interval for the size distribution of a species will depend on the extreme values of the size distribution, the type of analysis proposed, the purpose for which the data are to be used, and on the acceptable limits of accuracy of the information derived from them.

Data given in smaller length intervals can always be combined into larger groups in several ways. However, in order to ensure that data collected and presented by various workers can be pooled, it is suggested that the basic system of grouping agreed upon by the FAO Working Party on Tuna Length Measurements and Tabulation is adopted for general use. In this system, only specific length intervals are used, namely 0.5 cm, 1.0 cm, 2.0 cm, 4.0 cm, 8.0 cm, etc. For a specific class interval C, the successive classes are given by Cx_i ($i = 0, 1, 2, 3$, etc.). The scheme of combining into larger groups is presented in Table 1.

Table 1

Length interval		Groups with class intervals									
Equal to and greater than	Less than	0.5 cm m	0.5 cm f	1.0 cm m	1.0 cm f	2.0 cm m	2.0 cm f	4.0 cm m	4.0 cm f	8.0 cm m	8.0 cm f
				0.5	5						
0.5	1.0	0.75	5			1.0	21				
1.0	1.5	1.25	6	1.5	16						
1.5	2.0	1.75	10					2.0	96		
2.0	2.5	2.25	16	2.5	34						
2.5	3.0	2.75	18			3.0	75				
3.0	3.5	3.25	20	3.5	41						
3.5	4.0	3.75	21							4.0	373
4.0	4.5	4.25	19	4.5	46						
4.5	5.0	4.75	27			5.0	122				
5.0	5.5	5.25	34	5.5	76						
5.5	6.0	5.75	42					6.0	277		
6.0	6.5	6.25	48	6.5	92						
6.5	7.0	6.75	44			7.0	155				
7.0	7.5	7.25	32	7.5	63						
7.5	8.0	7.75	31								
			373								

In the above table, m represents the mid-point of the class and f the corresponding frequency in the class.

3.4 Method of Measuring and Recording

For some fisheries work such as stock discrimination studies, precise measurements of length and other characteristics are necessary. In such cases, fish samples are brought to the laboratory and measurements are carefully taken and are, therefore, reliable and precise. But for a sampling programme for the estimation of size composition of commercial catch, numerous length measurements are needed and they are made on selected fish samples under difficult field conditions. Usually catches are sold and removed by merchants within a very short time after they are landed and scientists, often remaining in a standing position all this time, may have to measure and record these measurements within a short period. It is thus essential to have a convenient, easy but reliable measuring device for field work and this is best done by using a standard type of measuring board. In the following paragraphs, a brief description of a standard measuring board is given and this is followed by a description of how it is used for measuring and recording fish in the field.

Measurements of "total length" are usually made with the fish lying on its right side, snout to the left, on a measuring board. This consists essentially of a flat wooden, plastic or metal platform with a central scale fitted on it and with a head piece (nose block) at the zero end of the scale against which the snout is gently pressed at the time of reading the the measurement. The board usually has a handle which makes it easy to carry. It must be both strongly constructed, and must also retain its accuracy after several years of use in adverse conditions (e.g., soaked in sea water, or mishandled or dropped). The scale must be

clearly marked and easy to read. If ink is used to mark the scale, it must still be clearly visible after at least one year, preferably longer. The scale must correspond to the unit of measurement decided for the specific species. It is impossible to measure fish to the nearest centimetre below on a board having a scale marked at 2 cm intervals. If, however, the scale has too many divisions, mistakes are likely to be made in reading the correct measurement in a hurry or too much time wasted. For fish measured in centimetre units, a 1-m board is usually sufficient, although it may be useful to have an extension piece 30 cm long, which can be clipped or hung on, if large fish frequently occur in the samples. For fish measured in 0.5 cm units, a half-metre board is usually sufficient.

To measure a fish, its mouth is closed and the fish placed flat on the board and the fish body and tail straightened along the midline before the reading is taken from the scale. Since fish shrink rapidly on dying, it should be measured while it is fresh and wet, i.e., as near to the relaxed live condition as possible. Normally, when fish are measured on board the fishing craft or in markets at the time of unloading, the problem of shrinking will not be faced. But if samples are taken away for measurement at leisure, such measurements may have to be converted to those of fresh and wet conditions by using a conversion factor or formula.

Fish in rigor mortis (stiffness after death) should be flexed gently before they are measured. In certain circumstances, for example, during tagging experiments, fish have to be measured alive. It may be necessary under these circumstances to use narcotics to relax the fish during handling. A solution of Sandoz MS 222 is widely used for this purpose. For live cephalopods, immersion in very cold sea water serves the same purpose.

Rays and other dorsoventrally flattened fish may be measured while lying straight on their ventral surfaces. Disc width (Figure 7) rather than total length is sometimes used as the dimension of rays. Large and flat fish present difficulties. Their lengths may either be measured with calipers (straight line measurements) or from point to point along the body surface with a tape (measurement along the curvature of the body). It may be noted that the curved measurement will always be greater, so it is necessary that method of measurement should always be specified.

Commonly, measuring is done by observers working in pairs, one of whom places the fish on the measuring board and calls out the length measurement after reading it, and the other man records the length usually in a specially designed recording book. A common source of error is indistinct calling by the measurer, causing the recorder to write down a wrong entry. Usually, fish are measured under adverse conditions, either in landing sites, fish markets or on board fishing vessels at sea, where there is always a lot of loud background noise. It is, therefore, important that the person measuring the fish should call out the measurements in a clear and distinct voice. If he does not do so, the person recording the measurements may not hear correctly the measurements being called out and make a wrong recording. It is equally important that the recorder should intervene and check with the caller when he notes that a measurement being called is somewhat different from the general run of other readings being called out.

Various techniques have been developed to allow one man to measure fish on his own. The simplest and cheapest of these is the use of a one-man measuring board (Williams, 1960). Figure 8 is a drawing of such a board showing the scale marked in centimetre units and a line drawn down its median axis to help keep fish straight during measuring. The scale is drawn with an ordinary pen using printers' ink grade HJ 150/A on a white matt surfaced plastic material, which is attached to the wooden board with an impact adhesive. The plastic surface is 0.02 in thick. It is supplied with one side polished and one side matt and it is necessary to roughen the polished side before attaching it ot the wooden board. Resin bonded marine plywood, approximately 18 mm thick is used to make the measuring board but hardwood would be equally suitable when measuring fish, each one being laid on the board with the head touching the upright headpiece. The fish is straightened so that it is parallel with the median line, and the length is recorded by a pencil mark in the centimetre space within which lies the extreme end of the tail or other point on the fish up to which measurement is

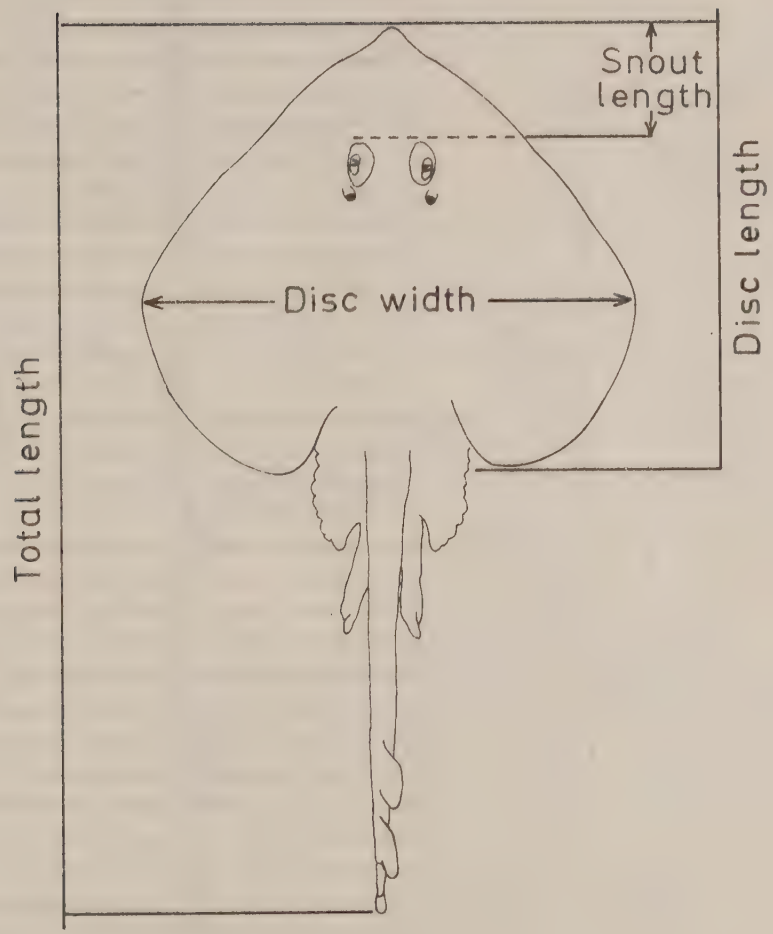


Figure 7 Method frequently used for measurement of size of rays

to be taken. The frequency distribution of the length measurements is built up by recording the marks of such measurements in appropriate centimetre spaces arranged in blocks of five (e.g., ⊠ or 𝍸). A soft pencil is used for recording the marks on the board and they can be removed with an ordinary pencil eraser. If, after use for some time, the board cannot be cleaned easily with an eraser, xylol applied with a soft cloth and rubbed hard will remove all pencil marks. This should not be done too frequently, as xylol also removes a little of the printers' ink each time. Figure 9 shows a series of lengths already recorded on the board and a fish being measured. Sample 1 has been completed, and is separated from Sample 2 by a line drawn by the measurer.

The method is similar to the one described by Davenport and Harling (1965), but instead of transferring the recorded measurements from the plastic board to a log book, they used a new graduated plastic strip pinned to the board on each occasion.

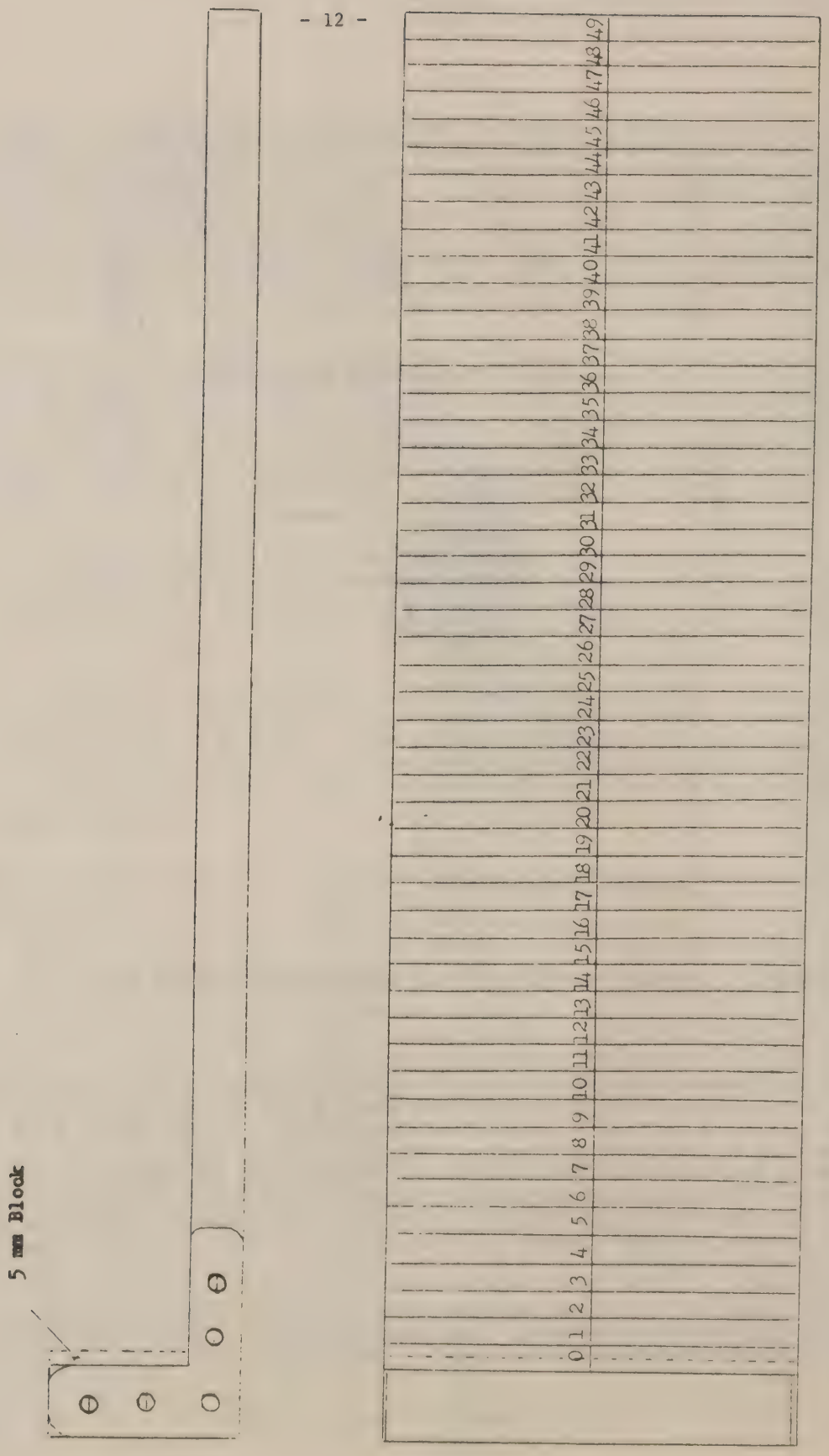


Figure 8 Standard measuring board

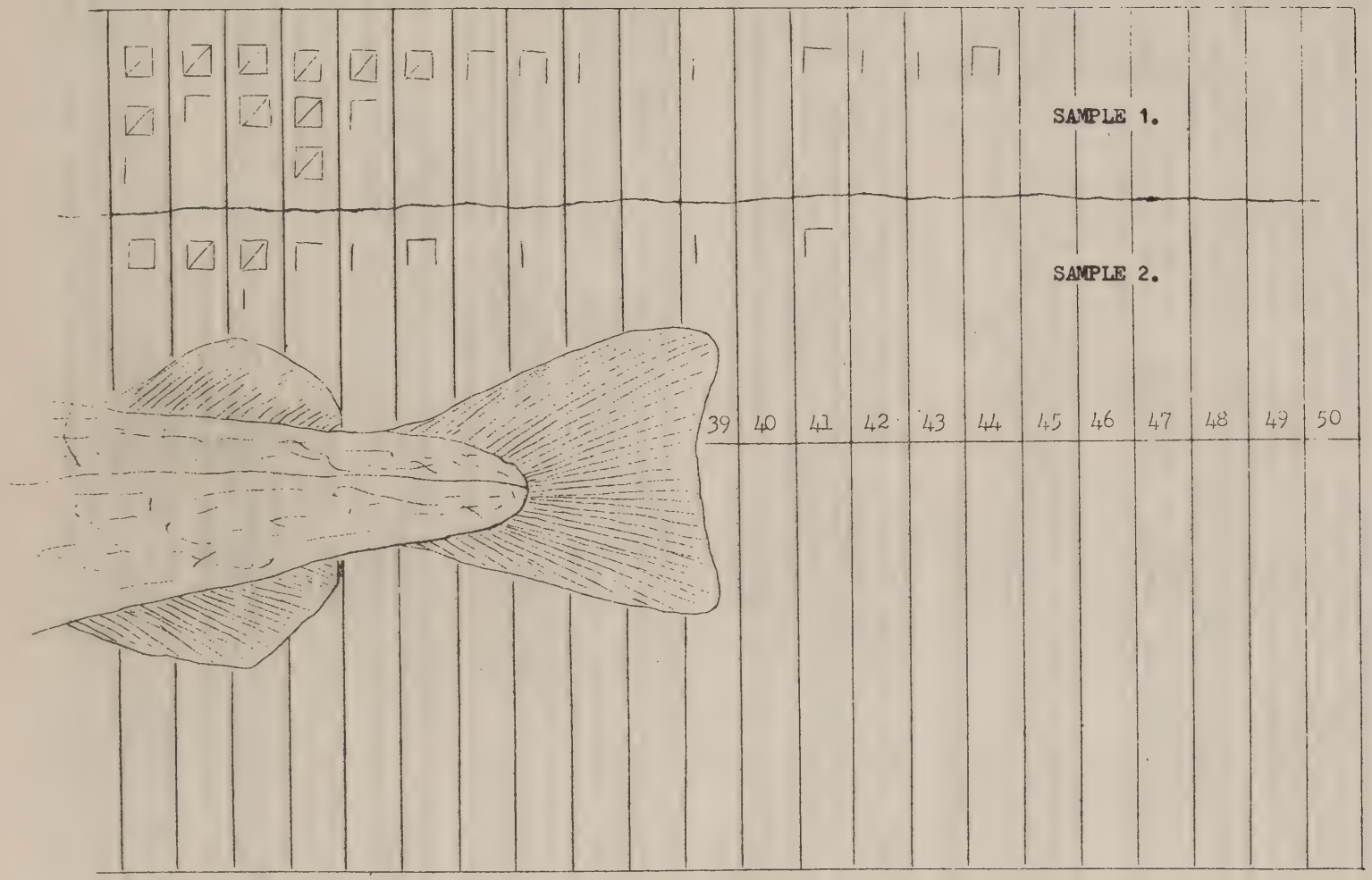


Figure 9 Measurements taken on a one-man board

Other somewhat more sophisticated methods are also in use now. The use of a small tape recorder slung around the neck of the observer will free both his hands for the measurement of fish. The tape recorder automatically records the measurements called out by the observer but the data transposition on paper is carried out on return to the laboratory. (Data transfer is done directly to frequency sheets.) Unlike the situation in the paired observer technique, the tape recorder cannot mis-hear and record wrongly, but the background noise recorded by the tape may sometimes make some, or the entire portion of the tape unintelligible, thereby resulting in the loss of information and introducing bias in the recoverable portion of the length measurement data. It is important that the tape recorder is reliable and well maintained. The batteries should be checked before each measuring programme. There is nothing more disappointing than to find on playing back that nothing has been recorded, or that whatever has been recorded is so indistinct that it cannot be decoded. Not only has the time spent measuring been wasted but it may be impossible to get the same sample of fish for remeasuring. Another disadvantage of a tape recorder is that it takes as much time in playing back, if not more, as was spent in measuring the fish.

Another recent technique of measuring fish, especially the large ones such as tunas where rapid measuring of length is impossible, is by photography. ICCAT has successfully used this technique in measuring quickly samples of large tunas. Before taking photographs, a measuring scale is put in the same focal plane as the fish to be measured.

3.5 Measuring Damaged and Processed Fish

Suppose it has been decided that the linear dimension to be measured for a specific fish is total length. If an occasional fish in a sample has its caudal fin damaged, it may be simpler to omit such a fish from the sample, but it may be quite likely that the damage to caudal fin is correlated with size, bigger fish being more liable to damage. Hence an estimate based on samples omitting the damaged fish may give a biased result toward underestimating the abundance of large fish. Hence it is advisable that instead of rejecting a damaged fish from the sample, replace it by an undamaged fish of about the same size and take its measurement. This will avoid bias in underestimating large size fish from the sample results.

If, however, all the fish of a sample or a large proportion of them are damaged or processed (e.g., if the heads have been removed or the fish have been dried), another convenient linear dimension should be measured and referred to comparable measurements in undamaged fish. The Peruvian anchoveta is a typical example of this type of problem. The larger fish have the least damage but the smaller fish are often so badly damaged that it is impossible to measure their total lengths and head lengths are measured instead. From samples of fish with both total and head length measurements, a linear relation is established between the two linear dimensions and either directly from this estimated relationship or from specially calibrated measuring boards, head lengths can be converted to total lengths.

The same type of problem was faced during an investigation of the Cape hake, *Merluccius capensis*. Part of the catch of Cape hake is landed headless and part with heads on. Williams (1967) describes the procedure for estimating the total length of headless fish.

Linear relationships exist between the total length (L_T) of fish and the magnitudes L_P (the length from the pectoral fin to the end of tail) and L_A (the length from anus to end of tail). These relationships were estimated from a sample of over 200 fish covering the whole of the length range with measurements of all three dimensions L_T, L_P and L_A taken from each fish. Mean size class values of L_P and L_A were plotted against mean size class values of L_T of total length to give two straight line relationships:

$$\bar{L}_P = 0.728\ \bar{L}_T + 0.788 \qquad (3.51)$$

$$\text{and}\quad \bar{L}_A = 0.568\ \bar{L}_T + 2.293 \qquad (3.52)$$

These fitted lines are shown in Figure 10. Relationships between the three measurements were then read from the fitted lines in the above figure and used to construct a specially calibrated measuring board that helps converting L_p or L_A into corresponding L_T.

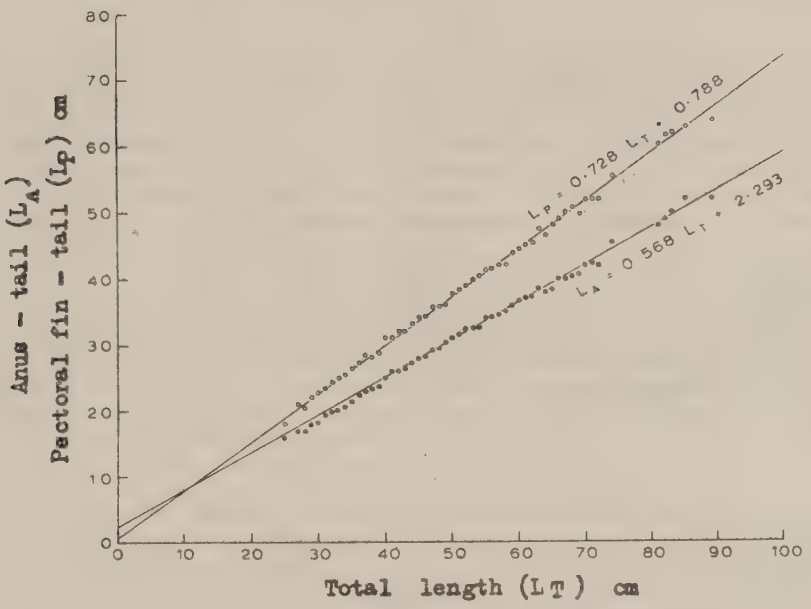


Figure 10 Relationship between L_T and L_p or L_A for South African hake

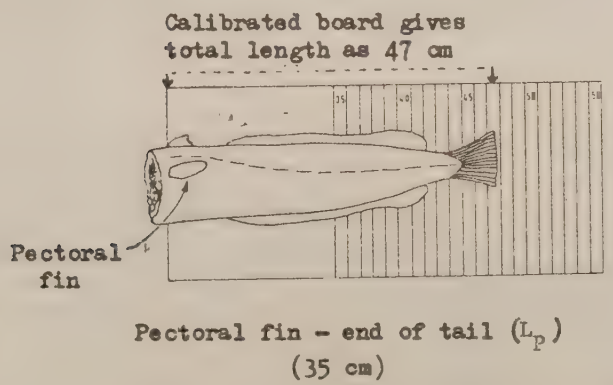


Figure 11(a) Measuring board graduated to give total length by measuring L_p

For the L_p calibration the board is graduated in units of 0.728 cm, each unit being equivalent to 1 cm of total length. Adjustment is also made to account for 0.788 in equation 3.51 by having the zero of the scale at a distance of 0.788 cm or $\frac{.788}{.728} = 1.08$ units away from the edge of the board (Figure 11(a)). Three examples are given (Figure 11(b)) showing Lp measurements being directly read as corresponding total length measurements.

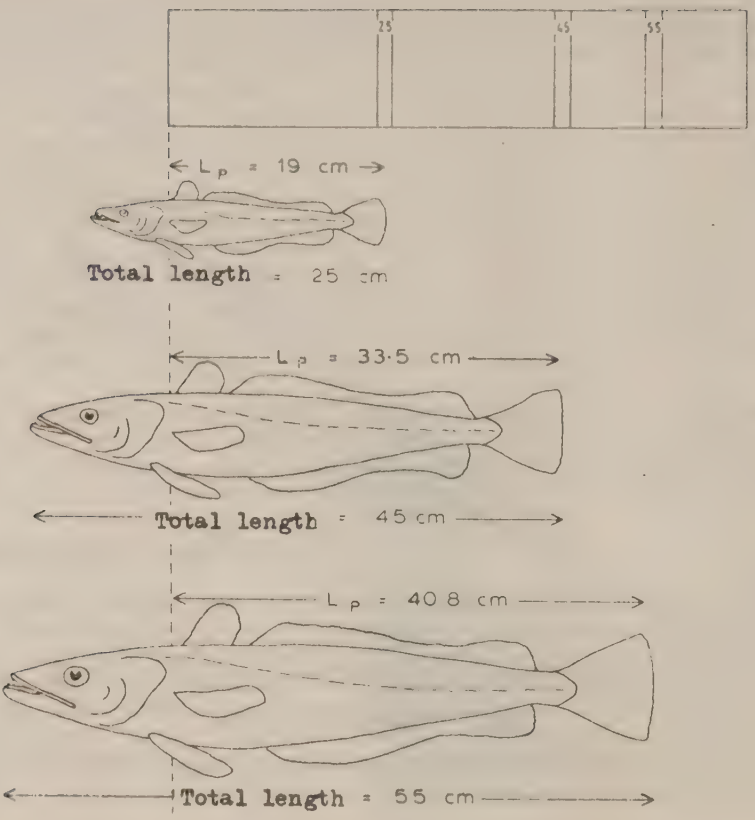


Figure 11(b) Three examples of L_p being directly recorded as total length

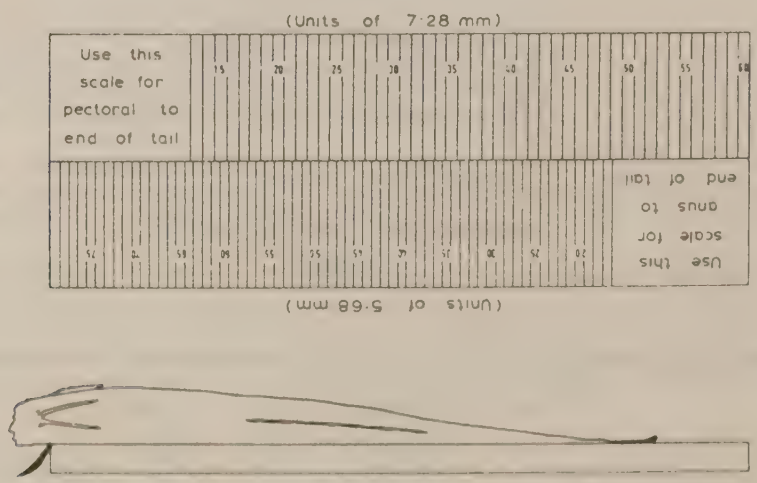


Figure 12 Calibrated board for measuring total length for both L_p and L_A

The regression coefficient for L_A is 0.568 (equation 3.52). For conversion L_A to L_T, the measuring board is calibrated in units of 0.568 cm with zero starting 2.293 cm away from the edge of the board.

A common measuring board for conversion of both L_A and L_P to L_T can then be devised by calibrating two sides of the board differently for the two characters to be converted (Figure 12).

In this way, total lengths of a large number of headless fish were measured quickly and easily and the size composition of the sample by total length was recorded directly without the need for any further conversion. It must be emphasized that the relationship between L_T and Lp and that between L_T and L_A given in equations 3.51 and 3.52 above refer to a particular stock of Cape hake only. They are not generalized formulae which can be used for any stock. It would be necessary to determine these relationships for any other stock or of any other species if the same type of problem arises and to construct relevant calibrated measuring boards for each stock unit independently.

When measuring headless fish, a board without a headstop is necessary because the base of the pectoral fin is placed against the end of the board; the fin being held at right angles to the fish. However, a normal board with headstop can be used for measuring total length of a whole fish, while the total length of the headless fish can be determined by placing the fish at the other end of the board without the headstop, but provided with a calibrated scale either in terms of Lp or L_A (Figure 13).

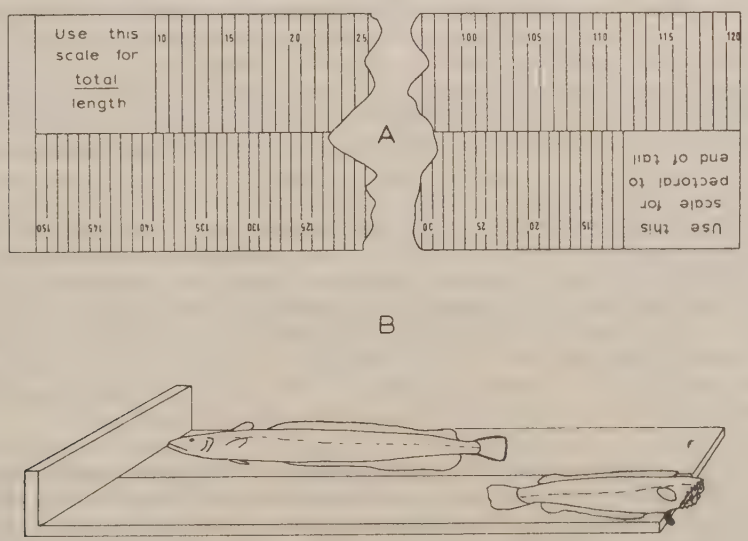


Figure 13 Measuring board for both total length of whole fish and total length of headless fish

3.6 Form for Recording Measurements

There are basically two designs of forms for recording length measurements. In the first design, the form provides for writing down length measurements in serial order as the fish are measured and later they are retabulated as a frequency distribution. This type of form is suitable when several attributes (e.g., length, weight, maturity, sex, etc.), are being recorded for the same fish. But normally it is much better to record in a manner that

produces a frequency distribution simultaneously. This may be done by having a form printed with the possible range of lengths down one side. As each fish is measured, a mark is made along the row of the appropriate length class in the form and the number at each length class can be simply totalled when all fish in a sample have been measured. Totalling is easier if the marks are grouped in fives (e.g., 𝍸 or ▨). An example of this type of form used for recording measurement of many specimens of the same species is shown in Appendix I. The main feature of this form is that only the units (0 to 9) are marked along the lefthand column. First, the size range in the sample is determined approximately to accommodate measurements of all fish within the range. Suppose, the approximate range is from 25 cm to 55 cm. Now, a '1' is the place the first zero should be made to make it read 10 and subsequent zeros made to read 20, 30, 40, 50, 60, etc. It would now be possible to record all the measurements of all fish in the manner described above. The other side of the form is used to record details of vessels, gear, date, place of landings, area fished and the quantity of all categories of species landed.

3.7 Reporting

Estimates of size composition of catch along with other data are needed for the assessment of the status of an exploited fish population. If a fishery is based on the exploitation of stock or stocks lying wholly within the national jurisdiction of a coastal country, and exploited by the fleet of the coastal country only, size composition data are of interest to only national scientists monitoring the stock or stocks. The question of reporting such data to any international organization or body does not arise. There may, however, still be the need for the storage of national data within the country either in published or unpublished form for later use. If common stock or stocks are being fished by several countries, however, their management and monitoring is of common interest to all countries exploiting the same stock and usually a commission is set up by the countries concerned and each member country is required to report to the commission the size composition and other related data of catch taken by it. With the introduction of the new regime of the sea, most resources will lie within the national jurisdiction of a coastal state, but other countries by arrangement may still continue to fish some of them. In such cases, the responsibility of management obviously devolves on the coastal state owning the resources, and reporting of data of all fleet fishing the resources should be made to some appropriate agency of the coastal State.

The purpose of reporting size and other related data by all fishing fleets is that they may be pooled for assessing the effect of total fishing effort on the stock or stocks. But before pooling data reported from different fishing fleets, it is necessary to ensure that such data are comparable and can be classified to refer to individual stocks being fished without any ambiguity. For comparability, it is essential to ensure that (a) the same length dimension is being measured and (b) the method of measuring and the unit of measurement adopted are the same for all fishing vessels. For relating reported data to individual exploited stocks, the following considerations should be borne in mind.

Size composition of catches from different stocks of the same species tend to be different because of inherent differences existing between stocks. Even when the same stock is being exploited, the size composition of catches may still be different for different fleets if they fish different segments of the same stock, e.g., the artisanal shrimp fishery of Kerala (India) exploits the smaller sizes of shrimps in the coastal area, and shrimp trawlers exploits larger sizes, of the same stock in the offshore area. Again it is common experience to find that the size composition of catches from the same area differs between seasons. This may be due to changes in the size composition of the stock due to spawning, growth, migration, etc. Fortunately, for most commercial fisheries, it may be possible to make a general delimitation of stocks by area and time. It is also common knowledge that, because of inherent differences in the selective properties of different gear, the size composition of catch by different gear, even when they are fishing the same stock, are different. Hence, it is essential that length composition data should be reported classified according to gear, area and time period (e.g., month or quarter). To enable reporting such classified data, it is obvious that collection of size data should be made after proper stratification of the fishery according to area, time and gear (see section 3.8).

Fishery commissions, set up to regulate and monitor a fishery exploited by several countries, have already laid down rules regarding the length dimension to be measured and the method and unit of measuring the same (section 3.1). They have also laid down the general considerations to be borne in mind (discussed in the preceding paragraph) in reporting length composition data for inclusion in Biological Sampling Yearbooks. An example of a reporting form used by ICES is shown in Appendix II.

Estimates of size composition of commercial catch which are usually reported are derived from data obtained from regular sampling at landing sites or at markets. As commercial catches are taken at preferred grounds using gear which are highly selective, the size composition of commercial catches do not in general represent the size composition of stocks from which such catches are taken, but do represent the composition of that portion being removed from stocks in the sea, and sometimes it is representative of the size composition of stocks beyond a certain size. Estimates of size composition of commercial catch are thus important and form the basic data for purposes of stock assessment. Sometimes in special resource surveys using research vessels, samples are collected from the sea from which estimates of either indices or absolute abundance of size composition of stocks are made. These estimates are distinct and separate from those estimated from sampling commercial catch and are kept separately (section 3.8.7). It is usual that data from such occasional sampling of catches of research vessels are tabulated as mille frequency distribution, i.e., as a proportion of 1 000, and are reported separately along with the following additional information:

(i) source (e.g., name of research vessel; cruise number; date, month and year of cruise);
(ii) gear used (including mesh or hook size);
(iii) number or weight of fish measured, and
(iv) number and weight of fish landed.

3.8 Sampling Programme for the Estimation of Length Composition of the Commercial Catch

It has already been stated in section 3.7 that estimates of length composition of commercial catches are usually made by sampling the commercial catches. These estimates are important and even though they are widely used in most assessments of stock, they are not in general indicative of the actual size composition of the natural fish population in the sea. Independent estimates of size composition of the natural fish population in the sea are generally obtained by occasional sampling of this natural population. In this section, we will first deal with the problems of sampling programmes of commercial catch and then we will discuss the problem of sampling the natural population in the sea.

3.8.1 Statistical objectives

Before considering the sampling procedure to be adopted for conducting a sampling programme for the estimation of the length composition of the commercial catch of a fish, it is necessary to clearly spell out the objectives of the sampling programme both in respect of extent and attribute to be examined. For example, the objectives may be to estimate the length composition of the annual landings of sardine along the west coast of India; or the length composition of plaice landed by UK trawlers from the North Sea; or the length composition of shrimp catches off the Atlantic coast of Mexico. It is necessary to clearly state the objectives to ensure full coverage of the target population we have in mind. In fact, the objectives define the target population which is to be covered by the sampling programme. Once the target population is known, the kind of fishing vessels which are covered by the sampling programme are also identified. Thus, for the objectives of estimation of length composition of plaice landed by UK trawlers from the North Sea, we are interested in plaice caught only in the North Sea by UK trawlers. Plaice landed in the UK from waters other than the North Sea are excluded. So also are plaice landed by vessels other than trawlers. Thus, in designing a sampling programme with the stated objectives in view, we need consider only those UK trawlers which fish for plaice in the North Sea and only those ports in the UK where the UK trawlers land North Sea plaice. For the problem of

estimation of size composition of oil sardine catch, we consider all vessels and gear that catch the fish and all landing sites on the west coast of India where such landings take place. For the shrimps caught off the Mexican Atlantic coast, we consider both indigenous and modern trawlers fishing for shrimps, and all the large number of small and a few fairly large landing sites.

3.8.2 Nature of the target population

It is not only necessary to identify the target population to be sampled, but it is also required to know about the nature of the target population. Such knowledge may help in adequate stratification of the population enabling us to design sampling programmes to obtain full gains of stratification. The following is a brief discussion of some of the special features of commercial fish landings, the length composition of which is required and which is therefore our target population.

Landings of a fish may depend on a fishery which may either be exploiting a single homogeneous fish stock, or may be exploiting several separate and discrete stocks occupying distinct areas in the sea. Since the size composition of fish may differ from stock to stock, it will be more efficient to construct sampling programmes based on stratification of the landings according to the area of capture (which will identify the stock from which the catch is taken). Thus, in Mauritius line fishing exploits the groundfish of several banks and size composition of the same fish is known to vary from catch of one bank to the other. Hence, in collecting length data, it is necessary to collect separate samples of fish caught from each bank. In most cases, boats exploiting separate stocks land their catches in landing sites close to the area of exploitation. In such cases, it may be enough if landing sites are stratified into several area strata and samples collected from each area stratum. But if catches caught from more than one stock are landed at the same landing sites by the same or separate vessels exploiting them, their stratification by landing sites will be of little use; it will be necessary to stratify the landings by area of capture.

Another example of spatial stratification is provided by the landings of a fishery which exploits the fish of the same stock both in the inshore and offshore waters. It is well known that, as shrimps grow, they migrate seaward and hence the size composition of the shrimps caught offshore will consist of larger specimens than those caught in the inshore waters. Hence it is reasonable to stratify the landings in such cases by depths of exploitation.

The size composition of fish caught by different gear may vary considerably. If a fish is exploited by several gear, it is necessary to stratify the landings by gear before they are sampled for size composition.

The size composition of fish in the commercial landings may vary considerably with seasons. This may happen, due to migration, growth or recruitment of young fishes to the fishery. Hence it is necessary to have time strata also before deciding on a sampling programme.

Hence in a sampling programme for the estimation of length composition, it is necessary to stratify the landings by using the proper criteria of stratification, i.e., by area of landings, area of capture (or by depths of the sea at the area of capture), mode of capture and season of capture. The more homogeneous the ultimate stratum is, the more efficient the sampling programme will be in the sense that a small size sample of each stratum will yield estimates of length composition with a small variance.

The ultimate stratum may be the landings made by gillnets in a particular district (comprising a number of landing sites) during a particular month, or it may be the landings at a port made by a line fishery in August of fish caught from a particular bank.

3.8.3 Types of sampling

For the purpose of sampling length composition data, samples may be collected either on board the fishing vessels, or at landing sites or even at wholesale markets which come next in the chain of fish distribution.

3.8.3.1 Sampling on board the fishing vessels

It is common experience that all fish caught are not always landed. Sometimes smaller specimens are discarded at sea, either because there is no market for them, or because there are legal restrictions on landing them. Thus, sampling of landings at the landing sites or at the markets may not furnish realistic estimates of the length composition of catch taken. Besides, in cases where fish are frozen on board the fishing vessels, the size of fish may shrink at the time of landings and hence size data collected at landing sites or markets may not truly represent the length composition of catch. Ideally, therefore, sampling for length composition of commercial catch should best be done on board the fishing vessels during the fishing operation. There are several practical difficulties with a sampling programme for collecting length data on board fishing vessels. First, it is difficult and costly to send scientists or fishery technicians or observers on board all selected fishing vessels in all their cruises even if the number of selected vessels is small. Scientists sent aboard vessels will not have full-time work. Next, most fishing vessels would not welcome the presence of scientists on board fishing vessels which are already cramped for space for fishing operations and accommodation of crew. It is unnecessary to mention that no one can be sent on board artisanal fishery vessels for such work.

3.8.3.2 Sampling at landing sites

The most convenient place for sampling fish for most fisheries is the site where fish are landed after capture. Since a number of boats land at a landing site within a short interval of time, it is possible for a single or a pair of fisheries technicians to examine and measure samples from several vessels within a short time.

Usually, the landing centres are grouped into several area strata so that types of vessels and gear operating from the landing centres in a stratum are more or less similar, and the nature and composition of the catch landed is also the same. During a month or some other suitable time period, one or two landing sites in a stratum should be selected strictly at random. However, this is not easily practicable since the randomly chosen centres may be quite some distance away from the place of work of the observer, and travelling to and from the centres and between them may take most of the time of the observer. The landing centre where the observer is normally located or posted, is obviously the most convenient centre for collection of samples, but it would not fulfil the condition of random selection. If, however, the vessels operating from all landing centres in the area stratum are similar, and are using the same type of gear and are also probably exploiting the same stock and therefore landing similar catches, there are no reasons why the length composition of landings at the convenient centre will be different from those in other centres. In fact, area stratification is based on such considerations, and therefore sampling can be carried out at the most convenient centre with occasional checks at other centres to make sure that the composition in other landing centres in the area stratum remain the same as in the sample centre. Before forming area strata, it is advisable to do pilot surveys to check the composition of catch.

The composition of catch may sometimes vary between centres if vessels from these centres fish in different areas containing possibly different stocks. The most practicable solution in this case would be to continue sampling at the convenient centre, but sampling may be done separately for each fleet fishing in different areas and combined after giving weights according to landings from each area of fishing.

3.8.3.3 Market sampling

Sometimes it may be difficult to collect samples even at the landing centres. For example, landings may take place at such odd hours that it is not possible for the fishery staff to be present at the landing centre and collect data. Wholesale markets are the next most convenient places for collecting and measuring samples. It must, however, be remembered that the further the sampling is removed from actual time of capture, the greater are the difficulties in collecting all details of catch (e.g., area of capture, method of capture, etc.). If some catches do not pass through these markets they have no chance of appearing in the sample. For example, fish for production of fish sauce usually consist of smaller specimens, and since they go direct to factories and not through the markets, market sampling may not represent the smaller specimens in the catch. Likewise, fish that are cured or dried are again composed of smaller specimens, and if they do not pass through wholesale markets, the size composition estimated from market samples will not represent that of commercial catch.

3.8.4 Sampling methods

Different sampling types have been described above and we will now briefly describe the methods of sampling for each of these types.

3.8.4.1 At landing sites

Sampling fish at selected sites for measuring length is conveniently done in two stages. First, a sample of one or more boats is chosen at random from the boats landing during the selected day or days and then a sample of fish is selected from each selected boat. The selection of boats is generally no problem; a non-random selection is not very harmful as long as time of landing or the position of landing is not correlated with the fishing ground and hence related to the size composition of the catch.

At the next stage, comes the sampling of the catch of the selected boats. The method of sampling will depend very much on the practices followed in landing the catch. In modern commercial vessels, usually the small fish caught are heaped together on the deck of the vessels and other larger fishes are put in containers such as boxes, baskets, etc. The catch of small artisanal vessels is generally stored in the boat and landed in standard boxes or baskets. The beach seine catches consisting of small pelagics are generally heaped on the beach. The method of sampling the small fish is dealt with first.

When the fish are lying in a large heap either on the deck of a vessel or on the beach and only a small number is to be selected as a sample from the heap and measured, it is necessary to adopt a method of selection which may almost be equivalent to a random selection. First, we deal with the case when the heap is composed of only one species. The usual tendency in the absence of a proper sampling system is to take the desired number of fish from the top of the heap and since such fishes are likely to be larger in size than others in the heap, estimates of size composition based on measurements of fish thus selected may introduce serious bias. Even when one is aware of the bias, it cannot be removed easily. Conscious selection of specimens from positions other than the top of the heap to compensate for selection from the top may sometimes introduce bias in the negative direction. There will be no bias if it is possible to measure all fish in the heap. If the heap is too large, the number may be reduced by measuring only a part of the heap, say 1/4 or 1/8 of the total. This may be done in several ways described below:

(a) One method is to insert a wooden divider or slab approximately through the middle of the heap, dividing it almost into two equal halves, and select one half at random. Arrange the selected half into a heap and divide it into two halves in the same way as before and select one at random and continue the process until a lot of desired size is obtained and all the fish in the lot are measured;

(b) A second method consists in dividing a heap into a desired number of smaller lots (the size of each lot being approximately the one in which all specimens can be measured) and then select one or two smaller lots at random and measure all fish in them. The division of a heap into a desired number of lots is effected by selecting specimens from the top of the heap, a few at a time, and allotting them to each lot successively, so that each lot will ultimately contain fish of assorted sizes;

(c) The third method consists of selecting fish by position in the heap. The heap is imagined to be divided into positional quadrants or segments and one segment is randomly chosen and all fish down to the bottom are measured in the selected segment, and

(d) A fourth method described by Bazigos (1973) recognizes that the fish in a heap are an auto-correlated population, i.e., neighbouring specimens in any position of the heap are similar in size. The heap on the deck or the beach is usually transferred to boxes or baskets with a shovel and when this is completed a few boxes (usually two or three) are selected and a small sub-sample of fishes from each box constitute the fish sample for length measurements.

It may be mentioned that none of the above methods of selection are really random, but they are designed to avoid bias in selection and the selected sample may, for all practical purposes, be taken as a random sample. When the heap is of mixed species, the procedure of selection of the sample remains the same as in the case of one-species landings but the size of the sample and the method of estimation will be different from those in the one-species case.

Catches of larger fish are generally placed in boxes, baskets or similar containers. One and two containers chosen at random generally form a convenient sample. If all the fish in the selected box are measured there would not be any bias but if it is decided to sample only a portion, fishes may be selected systematically with a random start from each box, i.e., if it is desired to measure only a quarter of the contents of a box, one of the first four fish brought out from the box is to be chosen at random and then every fourth fish taken out of the box. In the case of mixed species, the desired species may be sorted out first before further sub-sampling is done.

3.8.4.2 At wholesale markets

If there are a number of wholesale markets and it is not possible to cover them all, it will first be necessary to group them into area stratas, i.e., each stratum will consist of one or more markets which receive fish caught from more or less the same landing centres. Theoretically, one or more markets are to be selected at random, but in practice the market close to the place of work of the scientist may be chosen.

At each of the selected markets the arrival of the total number and quantity of the fish under study is noted. Then out of the total number of arrivals, a few arrivals are chosen at random and samples of the desired species are chosen from them and length measurements taken.

3.8.5 Sample size

One of the important problems in a sampling programme for length composition is to decide on the size of the sample to be taken, i.e., how many fishes are to be measured and if these are to be selected from a single landing or from many landings at a centre.

It is obvious that the number to be sampled will depend on the range of size distribution of fish landed. If all fish landed are of the same size, measuring only one fish is sufficient. If, on the other hand, the size range is quite large, a comparatively large sample will be required. If the range is, say, 20 cm and it is divided into 20 length groups

and if at least five specimens are required for the extreme length groups, the sample size may easily be as high as 200 to 500 fishes or even higher, depending on the relative abundance of the fishes of extreme length groups in the landings.

The sizes of fish in a single landing may not vary a great deal, especially if it consists of catch taken from a single haul or from the same fishing ground. Sizes may vary considerably between different landings as it is likely that vessels landing them may have fished different schools or fished in different grounds. Thus, in selecting a fish sample at a landing centre on a particular day, it is advisable to select some fish from many landings rather than selecting the desired sample size from a single landing.

Again, since the composition of a fish population being exploited may change with time due to growth, recruitment and migration, it is more efficient to collect samples spread over selected points of time than to collect a big sample on a single day.

Apart from the above theoretical considerations there are other practical considerations which limit the sample size to be taken at a centre on a given day. For example, there may be a limited number of staff or a limited fund for the purpose of collecting samples and measuring length. If, for instance, there is US$ 100 per month for buying fish or for the payment of measuring the size of fish in a sampling programme, and there are five landing centres at which samples are to be collected for four days in a month, then the amount available for collecting samples and measuring fish at a centre on a particular day is US$ 5.00, and this automatically limits the size of the sample to be taken.

3.8.6 Method of estimation

The ultimate aim of a sampling programme for measuring length is to estimate the length composition of commercial landings of fish. The method of estimation usually depends on the stratification used, and also on the method of selection of samples (e.g., sampling units selected in stages). In addition to data of length measurements of samples, we require estimates of the quantity of fish landed at various stages, to enable us to estimate the length composition of total landings. Estimates are usually made separately for each type of fishing unit for an area stratum, and added for all types of fishing units over all area strata. The various steps of computation for estimation are described below for the landings of a particular fishing unit in a particular area stratum for a particular species. For further information, reference may be made to Gulland (1966):

1. Measure the lengths of fish sample taken from a selected landing of a vessel at a particular landing centre in a month;

2. Compute the length composition of the landings of the selected boat from data in step 1. (Multiply the sample length composition figures in step 1 by a raising factor equal to the ratio of total catch of the boat by the weight of sample);

3. Add the results for all selected landings at that landing centre in the month;

4. Compute from step 3 the length composition of total landings at the selected landing centre in the month (i.e., multiply the length composition in step 3 by a raising factor equal to the ratio of the total monthly landings at the centre to the total landings by the selected boats);

5. Add together results for all landing centres in the area stratum (if more than one landing centre is selected);

6. Compute the length composition of monthly landings at all centres in the area stratum (i.e., multiply the estimated length composition in step 5 by a raising factor equal to the ratio of total monthly landings at the stratum by the total monthly landings at the selected landing centres), and

7. Add results for all months for annual estimates of length composition.

The same set of operations should be carried out for each type of fishing unit and the estimates summed up.

Exercise 3.8.6.1

A sample of 150 fish weighing 190 kg from a trawl landing at Bombay gave the following length composition:

Length (cm):	30-	40-	50-	60-	70-	80-	90-	100-	110-	Total
No. of fish:	39	58	28	11	5	3	3	2	1	150

If the total landing of the trawler was 4 500 kg, estimate the size composition for the total landing.

The raising factor is 4 500 ÷ 190 = 23.684. Multiplying the length composition of the sample, the estimated length composition of the trawler landings is obtained as:

Length (cm):	30-	40-	50-	60-	70-	80-	90-	100-	110-
No. of fish:	924	1 374	663	261	118	71	71	47	24

Exercise 3.8.6.2

Samples of *Polynemus tetradactylus* from five trawler landings in Bombay in September were taken and length measured. The length distribution of the samples together with their weights and the corresponding weight of total catch of *P. tetradactylus* in the five sample trawlers are given in the following table. Given that the total quantity of *P. tetradactylus* landed by trawlers in Bombay in September was 3 600 t, find the estimated length composition of this total landing.

Sample trawlers	*P. tetradactylus* catch (kg) of sample trawlers	Weight (kg) of sample taken	R.F.	Number of fish at different length groups (cm) in the sample 35-	40-	45-	50-	55-	60-	65-	70-	75
(1)	(2)	(3)	(4)	(5)								
1.	840	60	14	-	3	5	6	2	1	-	-	-
2.	910	130	7	2	4	10	8	5	5	2	1	-
3.	1 200	60	20	1	1	4	5	3	2	1	-	-
4.	750	50	15	-	-	3	7	4	1	-	-	-
5.	800	50	16	-	-	-	2	4	3	2	1	1
Total	4 500											

Raising factors for sample trawls are given in column 4 of the table and are obtained by dividing the trawler catch (col. 2) by sample quantity (col. 3) taken. Multiplying the sample length composition by the corresponding raising factors, we get estimated length composition of the total catch of the species in each trawler. They are shown below:

Sample trawlers	Estimated number of fish at different length groups for each trawler catch								
	35-	40-	45-	50-	55-	60-	65-	70-	75
1.	-	42	70	84	28	14	-	-	-
2.	14	28	70	56	35	35	14	7	
3.	20	20	80	100	60	40	20		
4.			45	105	60	15			
5.				32	64	48	32	16	16
Sample total	34	90	265	377	247	152	66	23	16
Estimated composition for Bombay (1 000)	27.2	72.0	212.0	301.6	197.5	121.6	52.8	18.4	12.8

The estimated length distribution figures for the five sampled trawlers are added up and the results multiplied by the raising factor $= \frac{3\ 600}{45} = 800$ to yield estimated length composition of *Polynemus* in all trawler landings in Bombay in September.

Exercise 3.8.6.3

Plaice landed at Lowestoft are generally sorted into two categories - large and small. During a certain period the total quantity of plaice landed was: large 4.50 t and small 23.04 t. One vessel was selected and its landings were: large 180 kg and small 2 880 kg and of these 60 and 18 kg of the two categories were measured and the following length composition was obtained:

Length group (cm)	25-	30-	35-	40-	45-	50-	Total
Large				16	33	15	64
Small	26	41	8				75

(a) Estimate the numbers in each length group in each category landed by the sampled ship, and

(b) Estimate the total number landed in each length group (i) by raising each category separately to the total landings, or (ii) by raising the total landings of the sampled ship of all categories. Comment on the two separate estimates (adapted from Gulland, 1966).

The raising factors for estimating the total landings by the sampled ship are: large category: 180 ÷ 60 = 3 and small category: 2 880 ÷ 18 = 160, giving the following estimated size composition for each category as well as for the total:

Length group (cm)	25-	30-	35-	40-	45-	50-	Total
Large				48	99	45	192
Small	4 160	6 560	1 280				12 000
Total	4 160	6 560	1 280	48	99	45	12 192

To estimate the total landings by all ships, using the data on the quantity landed of each category, the raising factors:

large category: 4 500 ÷ 180 = 25 and small category = $\frac{23\ 040}{2\ 880}$ = 8 are used.

Length group (cm)	25-	30-	35-	40-	45-	50-	Total
Large				1 200	2 475	1 125	4 800
Small	33 280	52 480	10 240				96 000
Total	33 280	52 480	10 240	1 200	2 475	1 125	100 800

Another estimate can be obtained by raising the total of samples by the factor: 27 540 ÷ 3 060 = 9, giving the estimate:

Total	37 440	59 040	11 520	432	891	405	109 728

The second estimate gives more small fish and less large fish. This is because the sampled ship landed proportionally more of the small category compared with the total landings. While both estimates are valid, the first one which takes into account the quantity of each category landed by all ships uses some information on the sizes of fish landed by all ships which were not sampled, and is therefore likely to be closer to the actual value.

3.8.7 Sampling the population in the sea

Sampling a fish population in the sea is quite different from sampling the commercial fish landings. Commercial landings are visible and observable entities, but the natural fish population in the sea is neither visible nor directly measurable. So, the various attributes of a fish population of a specific species, including the length composition, are estimated from sampling. Gulland (1966) has discussed in detail the problems of sampling a natural fish population.

Sampling is usually done from a research vessel. The main problem is the selection of a suitable gear. As there is no universal gear which will catch all species of fish from the sea, it is necessary to carefully select a suitable gear which will catch the species in the length distribution of which we are interested. It is likely that a single gear may not catch all the size groups of the fish and hence it may be necessary to use a set of gears.

Besides gears, the other main problem to be tackled in sampling is the patchy distribution of fish in the sea. Sometimes the distribution is segregated by size groups. This type of patchy distribution produces large variations between sample observations. The problem of high variabilities between sample observations can be overcome to some extent by stratifying the entire area of distribution of the fish into smaller subareas within which the distribution may be more or less uniform.

For a demersal species, depth is the most important criterion of stratification used. The abundance and the size of fish may change with depth in the case of these fishes. Obviously, stratification by depth will be useful in such cases. Other criteria of stratification used are related to the hydrography of the region.

The gain in efficiency from stratified sampling will be higher if more samples are taken from areas where the variation between hauls is high.

Once the area stratification has been done, sample hauls are taken from each stratum and the quantity and length measurements of the fish under study are measured. Estimates of either absolute number of fish of various length groups, or relative indices of various age groups, are obtained by subarea and later combined for the entire area of distribution.

It is important to briefly enumerate the various sources of bias and take care to see that they do not enter into the sampling system or into the method of estimation. The bias due to selection of gear has already been mentioned. The other most important single source of bias is the selection of sampling stations at sea. Ideally, these stations should be selected at random, but this is not always feasible, and in this case a grid system may be adopted. In this system, a systematic grid with lines of stations at regular intervals is the standard practice if for some reason a bathymetric chart is not available as a basis for randomly locating the stations.

The sampling positions should not be chosen with reference to the attribute being sampled, i.e., fishing hauls should not be made at only places of high abundance, however tempting this may be.

The number of sampling stations to be chosen is determined by three factors, namely, the variability between catches from different stations, the time taken to move between stations, and the time spent taking a sample at a station. As regards the variability factor, the precision of an estimate obviously increases with increase in the number of sampling stations. However, the number of sampling stations cannot be increased indefinitely, as it is generally restricted by the period of availability of the research vessel. In choosing the sampling stations, it has to be borne in mind that there will usually be more variability in catches taken between stations in different lines than between stations along a line. Thus, it is only natural that we should have more lines with a few sampling stations in each rather than a few lines with more stations in each line, but it should be remembered that a research vessel takes more time in moving between stations and hence total time is not increased greatly by having more stations in a line but it will be substantially increased if an extra line of stations is added. Thus, practical considerations of limited time will restrict the selection of the number of lines and the number of stations in each line in a grid system.

As a fish population is dynamic, at least in relation to the area it occupies, an estimate derived from a single survey is usually not enough. It is necessary to repeat a survey in the same area to understand the dynamics of the population. Dependent on the resources and funds, a balance has to be struck between detailed surveys in the area at longer intervals or less detailed surveys at shorter intervals.

The method of estimation is similar to one employed in stratified sampling, i.e., estimates are made separately for each stratum and are summed up for all strata. For each area stratum, the abundance is estimated by multiplying the mean density in each stratum by the total area of the stratum. Let:

A = area of a stratum;

n = number of sample trawl hauls in the stratum;

w = total weight of a species of fish caught in n sample hauls;

a = total area covered by n sample hauls, and

n_j = total number of fish of j^{th} size group of the particular fish in n sample hauls.

Then, assuming that each trawl haul catches all fish in the area covered by it, and that the density in the sampled area is a good measure of overall density, we get:

$\bar{d}_1$ = mean density of abundance (by weight) of the particular fish in the stratum

$= \frac{w}{a}$

and $\bar{d}_2$ = mean density of abundance (by number) of the j^{th} size group of the fish in the stratum

$$= \frac{n_j}{a}$$

Therefore,

$\hat{W}$ = estimated total abundance (by weight) of the fish in the stratum

$$= \bar{d}_1 \times A = w \times \frac{A}{a}$$

and $\hat{N}_j$ = estimated abundance (by number) of j^{th} size group of the fish in the stratum

$$= \bar{d}_2 \times A = n_j \times \frac{A}{a}$$

$$= n_j \times \frac{\hat{W}}{w}$$

4. SAMPLING FOR WEIGHTS

In some cases, such as for squids, because of body plasticity (see section 3.2.1), it is easier to take measurements of weight rather than length in sampling at landing sites or at markets. Weights are generally taken by steelyards or spring balances. The former are sensitive to temperature changes and many other factors but small pocket size spring balances are useful instruments for measuring fish weight in the field, although they should be frequently calibrated, and are difficult to read accurately on board a moving boat.

Data on weights are converted to lengths by using a length-weight relation which is obtained on the basis of both length and weight measurements taken from a small sub-sample of fish brought to the laboratory.

The length-weight relation is also used for many other purposes such as for converting weights of fish to number of fish and for converting lengths of fish to weights and vice versa.

The general length-weight relationship for fish is curvilinear and of the form:

$$w = a\, l^b \qquad (4.1)$$

The above equation can be converted to a linear form by taking logarithms of both sides

$$\log w = \log a + b \log l \qquad (4.2)$$

i.e., $$y = a_1 + bx \qquad (4.2.1)$$

where $x = \log l$, $y = \log w$ and $a_1 = \log a$

The values of a and b of equation 4.2.1 are usually determined by the method of least squares from the available logarithmic data of length and weight of a fairly large number of fish of various sizes. The least square estimates of a_1 and b are given by:

$$b = \frac{\Sigma xy - \frac{\Sigma x \,.\, \Sigma y}{n}}{\Sigma x^2 - \frac{(\Sigma x)^2}{n}} \qquad (4.3.1)$$

$$a = \frac{\Sigma y}{n} - b\,\frac{\Sigma x}{n} \qquad (4.3.2)$$

The regression coefficient r between x and y is given by:

$$r = \frac{\Sigma xy - \frac{\Sigma x \,.\, \Sigma y}{n}}{\sqrt{\{\Sigma x^2 - (\Sigma x)^2/_n\}\,\{\Sigma y^2 - (\Sigma y)^2/_n\}}} \qquad (4.3.3)$$

and the variance of b is given by:

$$v(b) = \frac{\Sigma(y-\bar{y})^2 - \frac{\{\Sigma(x-\bar{x})(y-\bar{y})\}^2}{\Sigma(x-\bar{x})^2}}{(n-2)\,.\,\Sigma(x-\bar{x})^2} \qquad (4.3.4)$$

In the past, extensive data on length and weight were very often grouped into small length classes and the mean lengths $\bar{x}_i$ and mean weights $\bar{y}_i$ of the i classes were used in computing the regression line (4.2). The only motive in using this method was to speed up computation but it is impossible to compute v(b) when this method is used.

Example 4.1

The following table gives the length (cm) and weight (g) of 50 specimens of herring caught in purse seines. Find the length-weight relationship:

l	w	l	w	l	w
17.2	74	18.7	100	19.8	111
16.8	62	19.3	106	19.1	110
16.2	64	18.1	82	20.9	143
16.3	52	19.1	100	19.3	110
16.1	58	17.0	75	17.7	91
15.4	48	18.0	96	20.1	134
16.1	57	19.3	110	19.7	120
16.4	55	17.9	85	20.8	159
17.3	73	19.3	115	20.1	120
19.7	119	19.7	125	19.5	115
19.0	106	19.2	118	21.0	145
18.8	101	19.7	118	21.0	141
18.2	92	19.8	124	21.5	156
18.1	92	19.3	115	21.7	146
18.8	91	20.6	142	22.0	177
19.6	117	19.7	119	22.0	164
		20.2	136	20.7	146

The logarithmic transformation of the above data is given below:

x	y	x	y	x	y
1.236	1.869	1.272	2.000	1.297	2.045
1.225	1.792	1.286	2.025	1.281	2.041
1.210	1.806	1.258	1.914	1.320	2.155
1.212	1.716	1.281	2.000	1.286	2.041
1.297	1.763	1.230	1.875	1.248	1.959
1.188	1.681	1.255	1.982	1.303	2.127
1.207	1.756	1.286	2.041	1.294	2.079
1.215	1.740	1.253	1.929	1.318	2.201
1.238	1.863	1.286	2.061	1.303	2.079
1.294	2.076	1.294	2.097	1.291	2.061
1.279	2.025	1.283	2.072	1.322	2.161
1.274	2.004	1.294	2.072	1.322	2.149
1.260	1.964	1.297	2.093	1.332	2.193
1.258	1.964	1.286	2.061	1.336	2.164
1.274	1.959	1.314	2.152	1.342	2.248
1.292	2.068	1.294	2.076	1.342	2.215
		1.305	2.134	1.316	2.164

From the above table, we have:

$n = 50$
$\Sigma x = 63.896$
$\Sigma y = 100.712$
$\Sigma x^2 = 81.72599$
$\Sigma y^2 = 203.80998$
$\Sigma xy = 128.95911$

The corrected sums and squares (measured from means) are:

$$\Sigma(x-\bar{x})^2 = \Sigma x^2 - \frac{(\Sigma x)^2}{n} = 81.72599 - \frac{(63.986)^2}{50} = 0.07201$$

$$\Sigma(y-\bar{y})^2 = \Sigma y^2 - \frac{(\Sigma y)^2}{n} = 203.80998 - \frac{(100.712)^2}{50} = 0.95184$$

$$\Sigma(x-\bar{x})(y-y) = \Sigma xy - \frac{\Sigma x \cdot \Sigma y}{n} = 128.95911 - \frac{63.896 \times 100.712}{50} = 0.25723$$

Therefore, from equations 4.3.1 and 4.3.2:

$$b = \frac{0.25723}{0.07201} = 3.5721$$

and $$a = \frac{100.712}{50} - 3.5721 \times \frac{63.896}{50} = -2.5506$$

and from equation 4.3.4

$$v(b) = \frac{.95184 - \frac{(.25723)^2}{.07201}}{48 \times .07201} = \frac{.03208}{3.45648} = 0095414$$

and the standard error of b is given by:

$$S_b = \sqrt{.0095414} = .09768$$

Ordinary predictive regressions are used when x observations are not subjected to natural variability and are known accurately, i.e., they are independent variables. Functional regressions are used when both x and y are subjected to natural variability and none of them are independent variables (Ricker, 1975). The functional regression b' of y on x is given by:

$$b' = \frac{\sqrt{\Sigma y^2 - \frac{(\Sigma y)^2}{n}}}{\Sigma x^2 - \frac{(\Sigma x)^2}{n}} \qquad (4.1.1)$$

and the v(b') is given by the same formula of v(b).

In example 4.1 the estimate of functional regression coefficient b' is given by:

$$b' = \sqrt{\frac{0.95184}{0.07201}} = 3.636$$

which is not very much different from the estimate of ordinary regression coefficient b.

The standard error of b' is as before 0.09768. It may be noted that, unlike the example given above, the functional regression coefficient is often very different from usual predictive regression coefficient.

5. AGE DETERMINATION

It is essential to determine the age of fish for estimation of the rate of growth as necessary input to an understanding of the population dynamics of a species. Knowledge of the correct age of fish is essential in solving such life history problems as longevity, growth rate or ages at maturity or spawning.

The general methods of ageing fishes can be broadly divided into direct and indirect methods. The direct method of determining age is based on interpreting the layers deposited in the hard calcareous parts of the fish. Most attention has been given to interpretation of layers which correspond to annual events (particularly the check in growth during winter), but other types of mark, e.g., those corresponding to spawning, are also of interest. By far the most important structure employed for the purpose is the scale, with the otolith (ear stone), spine and bony structures such as vertebra, the dentary bone and cross sections of other bony structure, following in that order, though in the North Atlantic the use of otolith for ageing is most usual, because of clarity of the rings, and the absence of wear around the edge, as for some scales. These methods can be applied to fish of those species in which changes occur in the rate of growth or metabolism during certain periods of the year which leave their evidence in the skeletal structures. Accuracy in determining the age is dependent on the ability to interpret these layers correctly. Clarity of the layers varies with species and skeletal structure.

Many fish, especially those of tropical waters, live in a more or less uniform environment, and regular macroscopic changes do not always occur in the skeletal structures of such fish and thus direct ageing of these fish is often difficult or impossible. However, even here dramatic intrinsic events such as for example, slight decrease in salinity during monsoon season, or the onset of spawning, may be recorded on the skeletal structures.

The most common and widely used indirect method for age determination is the length frequency method or, Petersen method as it is usually called. This method is based on the fact that lengths of fish of one age tend to form a normal distribution and average sizes of fish at successive ages can be determined from the various modes of the polymodal curve. (Recent works, however, suggest that microscopic examination of thin sections of otoliths from fish of both temperate and tropical waters can reveal daily growth rings. An analysis of these daily growth units, although a difficult and time-consuming process, may provide a method for determining early growth in fishes and be particularly useful for fish of tropical waters which do not show annual rings in their skeletal structures (Brothers, Mathews and Lasker, 1976).

The other important indirect method of determining the age of fish is by the method of liberation and recovery of marked or tagged fish. We will first describe the indirect methods and then deal with the direct methods used for age determination of fish.

5.1 Indirect Method of Age Determination

This method is widely used for fishes of both tropical and temperate waters. In the case of fish of tropical waters, since skeletal structures generally do not exhibit changes of growth, this is probably the main method which offers some estimates of age and growth. The method is also in use in the case of fishes in temperate waters to check the validity of age readings from hard structures of the fish.

5.1.1 Petersen method

Petersen (1892) pioneered two simple methods for indirectly determining the age and growth of fish. The first method consists of attributing approximate ages to the various 'peaks' or modes of a single length frequency sample. The second generally called "Modal Class Progression Analysis" consists of following the progression along the length-axis, of the peaks in a series of length frequency samples sequentially arranged in time.

The method can be used with species which have a restricted spawning season so that the fish bred in a single season can be identified as a single mode in a polymodal length distribution. The mode with the lowest value is identified as soon as possible after spawning: these will usually be 0-group fish. (0-group means that another annual spawning has not taken place since these fish spawned.) Subsequent modes will be 1-group, 2-group fish and so on. The method can be very good for young fish but becomes increasingly less useful for older fish as the growth rate slows down and the modes merge. The method does not work if the spawning period or the period of recruitment is prolonged or if there are big differences in growth rates of fish of the same age. The traditional use of this method for tropical fish often generates questionable results as the spawning season of tropical fish are often quite long and spawning may occur in several batches, each later resulting in a peak in the length frequency distribution. Pauly (1980) has, however, developed an objective computer method which selects, among many possible growth curves passing through peaks in the sequential series of length frequency, the one which passes through most peaks. George and Banerji (1964) essentially followed the same approach in estimating age and growth of Indian mackerel.

Figure 14 represents the length frequency curve of a sample of *Sardinella aurita*. This is a tropical species which is not easy to age using either scales or otoliths. However, the length frequency distribution of purse seine catches shows two modes, one at 11.5 cm, which are the 0-group fish, and the other at 18.5 cm, which are the 1-group fish. Almost certainly all the fish less than 14 cm long are 0-group fish and fish between 16 cm and

19 cm are 1-group fish. Fish between 14 and 16 cm might either be fast growing 0-group fish or slow growing 1-group fish. There is another mode between 22 cm and 24 cm, and this is probably composed of 2-group fish. The presence of another small mode at 25.5 cm indicates that 3-group, and possibly older fish are also present in the population. However, sufficient information is available to determine approximately the growth rate of the species. The length composition can also be divided into its component age groups approximately by drawing smooth curves through the points where the modes overlap, starting with the youngest age group. The numbers of fish below the curve are allocated to the youngest age group and the remaining fish to the next oldest age group. This process is repeated until all the fish have been allocated to an age group.

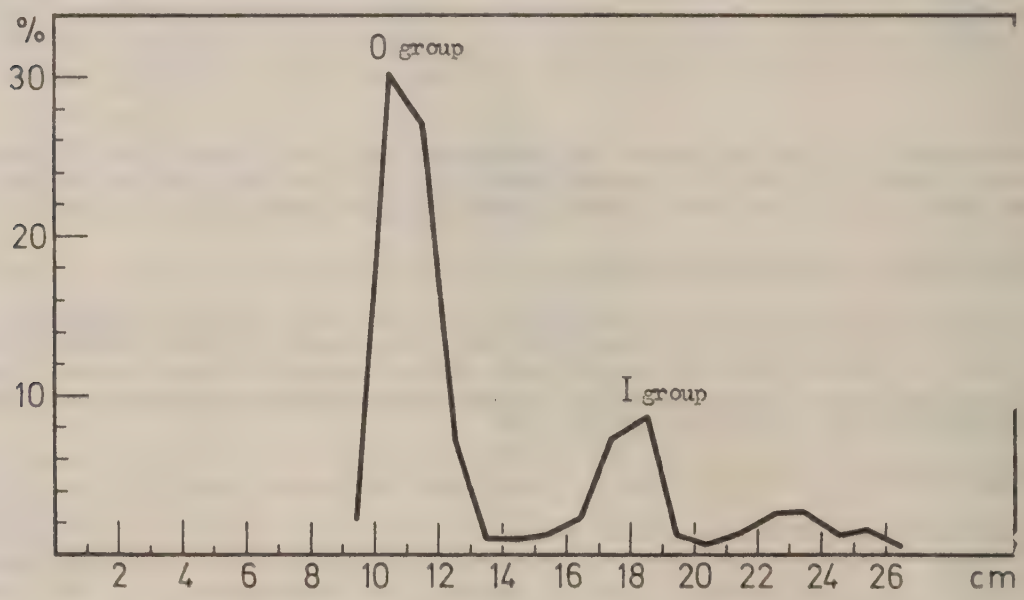
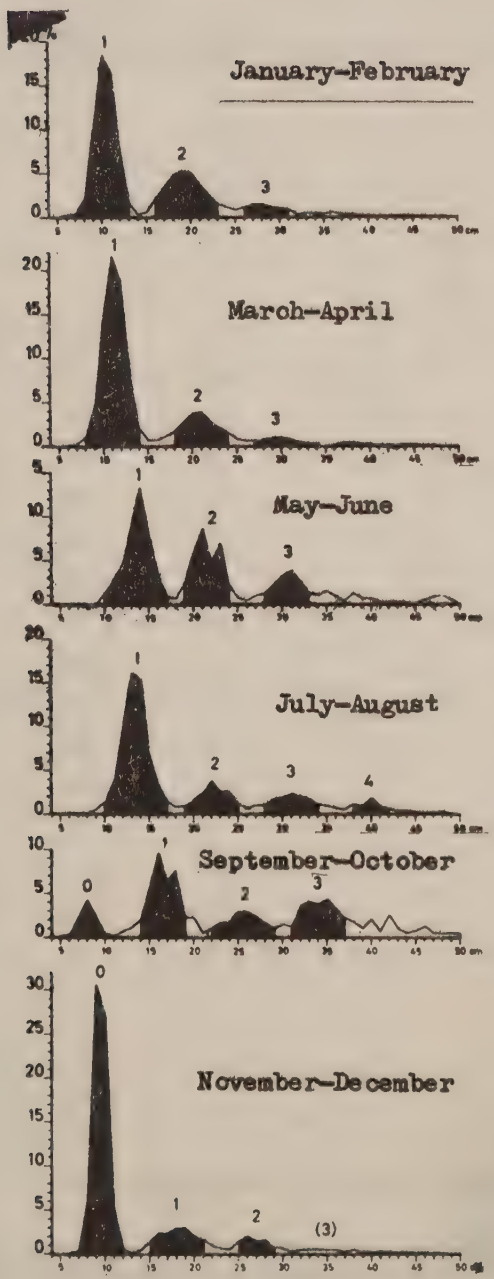


Figure 14 Length distribution of *Sardinella aurita* from purse seine landings

Another example is that of the Arctic species, *Reinhardtius hippoglossoides*, the Greenland halibut. It is impossible to age this species using skeletal discontinuities, but the length frequency distribution gives a good estimate of the length of 0, 1, 2 and 3 group fish, as shown in Figure 15. Furthermore, it is possible to follow the growth of the age groups throughout the year.



The age of this Arctic species can not be determined by the use of otoliths and scales, but the length distribution gives a good estimate of the length of 0-, I-, II- and III-group fish. Furthermore, it is possible to follow the growth of the year-classes during the year (data from Smidt, 1969).

Figure 15 Seasonal length frequency distributions of Greenland halibut

Exercise 5.1.1

The following table gives the length frequency distribution of fish sampled in five months during a year. Draw the length frequency curves and make estimates of growth and age.

Class interval	Frequencies Jan.	Mar.	May	July	Sept.
7 -	-	-	-	-	-
8 -	3	1	-	11	-
9 -	9	-	-	7	-
10 -	24	2	-	-	-
11 -	27	16	7	-	-
12 -	21	24	4	1	4
13 -	14	37	11	7	15
14 -	12	42	17	11	13
15 -	8	41	19	28	26
16 -	11	33	23	26	26
17 -	11	21	20	29	23
18 -	14	19	18	31	34
19 -	18	21	7	30	32
20 -	10	15	5	27	31
21 -	11	18	9	13	21
22 -	11	17	2	8	17
23 -	16	24	6	9	15
24 -	6	20	12	16	18
25 -	2	17	9	4	9
26 -	9	12	6	2	3
27 -	4	13	3	3	6
28 -	1	8	4	5	3
29 -	1	5	?	-	1
30 -	3	8	2	4	1
31 -	-	2	1	-	-
32 -	1	1	-	-	2
33 -	-	-	1	-	1

Figure 16 represents the length frequency distribution curves based on sample observations recorded above. Let us assume that it is known that the fish spawns once in January. The mode (a) at 8 cm in July, length frequency curve may then be interpreted as the group of small fish that was spawned in January. Since in January, the first mode (b) is at 11 cm and as small fish were already seen as an 8 cm group, it is likely that this group has grown up to 11 cm by January. Thus the average size of fish at one year of age is 11 cm.

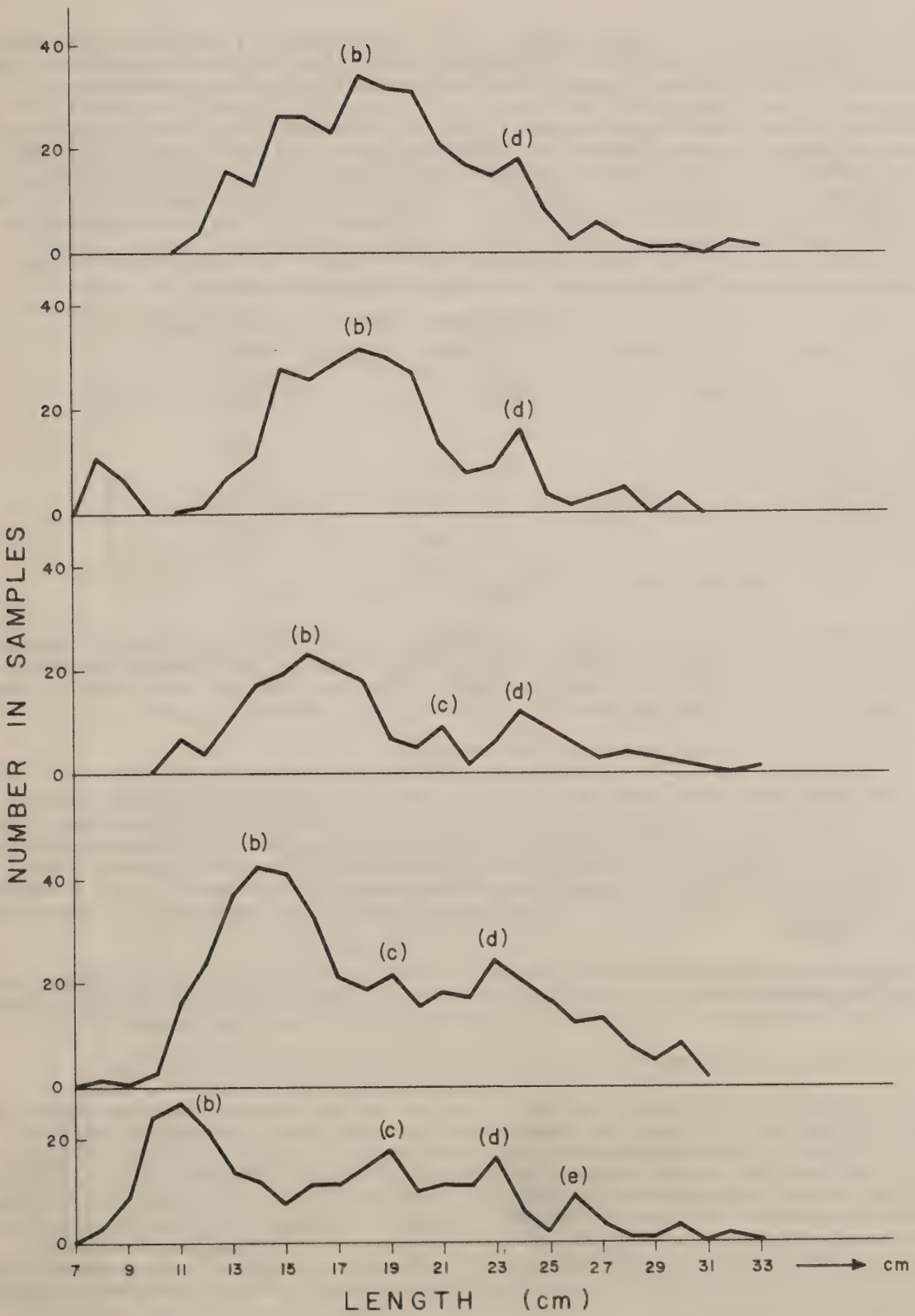


Figure 16 Length frequency distributions of fish sample measurements in different months (Exercise 5.1.1)

The mode (b) at 11 cm in January moves on to 14 cm in March, 16 cm in May, 18 cm in July and stays at 18 cm in September. It may be presumed that this mode has moved to the mode at the 19 cm position in January. Thus, the average size at two years is 19 cm.

The mode (c) at 19 cm in January moves to 21 cm in May and is not clearly seen thereafter in the length frequency curves of July and September. It may be presumed, however, that this group has grown to 23 cm by January next and may be identified with the mode (d) seen in that month. Mode (d) moves from 23 cm in January to 24 cm in September. It is not very clear if this is identified with mode (e) which appears at 26 cm in January and is probably four years old.

The growth pattern from the above interpretation is as follows:

Months	Growth	Monthly growth rate (cm)	Monthly growth rate on annual basis
0- 7 (7)	8	1.14	0.9
7-12 (5)	3	0.60	
12-21 (9)	7	0.77	0.7
21-24 (3)	1	0.33	
24-29 (5)	2	0.40	0.3
29-36 (7)	2	0.28	
36-45 (9)	1	0.11	0.1 (?)

The monthly growth rates on annual basis figures in column 4 are obtained by dividing the figures in column 2 by the figures in brackets in column 1. Even though the samples were not large, we get fairly reasonable estimates of growth rates and also some idea about the average size of the fish at least for the first three years of its life.

5.1.2 Resolution of a polymodal length frequency curve

It has been noted above that the frequency distribution of length obtained from a sample of fish is usually skewed and polymodal, that each mode usually corresponds to individual age groups, and that it is very useful to separate these modes. Various approximate methods have been suggested by fishery workers (Buchanan-Wollaston and Hodgeson, 1929; Harding, 1949; Cassie, 1954) for separating the components of a polymodal length frequency curve. Bhattacharya's method (1967) is very simple, and a brief description of this method is given in Appendix III.

Pauly's (1980) computer method of selecting the growth curve that passes through most peaks in a sequential series of length frequency curves provides another objective method of resolution of polymodal curves and of identifying the different age groups.

5.1.3 Following the progression of a successful spawning

It has already been stated in section 2 that in case of fishes of tropical waters there are several spawnings in a season or spawning may be sufficiently continuous and it is difficult to separate modes representing age groups in such cases. In fact, the length frequency curve drawn from measurement of fish samples from such a fish population may not show any distinct mode. Sometimes due to changes in environment or other reasons, a particular spawning may be very much more successful than usual. The progeny from this spawning will then show as a mode in the length frequency distribution, this may persist for several successive months and years. By following the progression of the mode in successive length frequency distributions, it will be possible to determine approximately the size at different ages.

5.1.4 Tagging

The most direct and positive way of determining the growth of fish is by liberation and recovery of marked or tagged fish of known size. When these fish are subsequently recaptured there can be no doubt, provided accurate records have been kept, as to the size of each specimen. The high value of this method lies in checking the scale or Petersen method, as marking or tagging fish often becomes a costly and time-consuming operation considering the low percentage of return. It may, however, be noted that the growth pattern of tagged fish may be slightly different from the untagged ones in the natural population. Figure 17 shows the relation of length at tagging against length at recapture for English soles. The relation is linear. It will be shown later that from this linear relation it is possible to compute estimated lengths at different ages (shown as open circles in the figure).

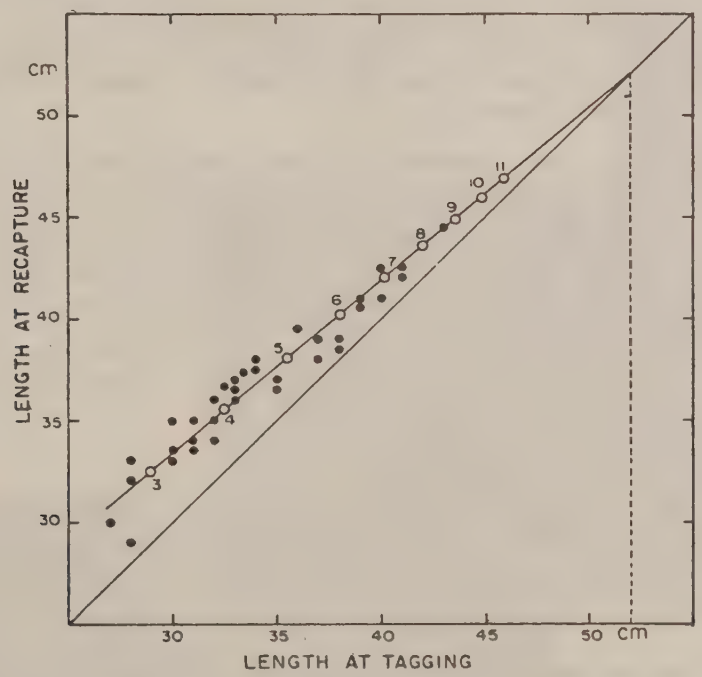


Figure 17 Length at tagging plotted against length at recapture for English soles

Gulland and Holt (1959) describe the method of fitting growth curves to data from the recapture of marked fish. From the fitted growth curve, estimated sizes of fish at different ages are obtained.

5.2 Direct Method of Ageing of Fish

Almost every skeletal structure has been used for age determination of fish. Of these, otoliths and scales are the most widely used because they are easy to collect and store (Williams and Bedford, 1974). The thin bones of the head and of the pectoral and pelvic girdles have also been used. Although bones are easy to store dry, they are time-consuming to prepare. The flesh has to be removed by boiling them in water and then the fat removed in a solvent, otherwise they go rancid in storage. Vertebrae are commonly used for rajids, which do not have large bony otoliths, and for tuna. Again these need time-consuming preparation. Ray vertebrae have to be cleaned in a boiling solution of sodium hydroxide and then stored in methanol. Tuna vertebrae are stored dry. Spines of the dogfish, *Squalus acanthias*, are also used for regular age determination of this species in England. When starting an investigation it is worth examining several different structures to see which gives the best results. In some instances two methods will complement each other.

As otoliths and scales are the two structures most widely used for age determination, only methods for reading these will be described. Most of these methods are equally applicable to reading the other structures with either no or slight modification.

5.3 Collection of Otoliths and Scales

5.3.1 Otoliths

The saggital otolith is that used for age determination of most fish. It is located in the sacculus of the inner ear. The manner of cutting into the head of the fish to remove it depends on the type of fish. It may also depend upon whether the fish are to be sold subsequently, in which case damage to the fish must be kept to a minimum.

For flatfish a cut in the position illustrated in Figure 18(a) exposes the otoliths which are then easily withdrawn with forceps (Figure 18(b)). When otolithing large numbers of flatfish the operation is speeded up by using a board with a slot, 3 x 10 cm, cut in the surface. The point of incision in the head of the fish is laid on the board over the slot; this enables the knife to be driven easily through the skull at point X (Figure 18(c)), and the cut made cleanly in the correct position.

A number of methods can be used to extract otoliths from 'roundfish', e.g., gadoids, the simplest being a transverse cut across the head, slightly behind the eyes, far enough into the skull to allow the head to be broken open. A knife or scalpel can be used for small fish but a normal metal hacksaw for larger sizes makes the operation quick and easy (Figure 19). An inexperienced work can easily cut too deeply and damage the otoliths, but the right technique is soon learnt with experience. An alternative method is to lift off the top of the skull. This is a more difficult method, particularly with large fish, although there is less chance of damaging the otoliths (Figure 20(a)). If the otoliths must be removed without apparent damage to the fish then it is possible to extract them from under the gill (Figure 20(b)) or from the roof of the mouth.

5.3.2 Scales

The scale lies in a pocket in the skin of the fish and is divided into two areas. The embedded area is covered with striations and concentric rings, while the exposed area is unstriated (Figure 21(a)). Scales vary in shape depending on the contours of the fish. The best scales for age and growth rate determination are generally to be found on the shoulder of the fish between the head and the dorsal fin (Figure 22).

The fish from which scales are to be taken should first be washed under cold running water. During the washing, the body of the fish should be rubbed lightly in a head-to-tail direction in order to remove any loose scales which may have rubbed off other fish. If this is not done errors will result. Using forceps, a scale is then taken from the shoulder of the fish. A slight resistance should be felt when it is pulled from its pocket in a head-to-tail direction. If no resistance is felt or if the scale is not observed to pull from its pocket, it is probable that it does not belong to that fish and it should be discarded. When a satisfactory scale has been taken, it should be cleaned by dipping in fresh water and rubbed between thumb and forefinger to remove any dirt or mucus. If sufficiently large, it should then be quickly examined by eye to check that the area covered with concentric rings is not damaged, as shown in Figure 21(a). Sometimes a scale is removed from its pocket at some stage in the fish's life; when this occurs, a new one is grown very quickly, but the new scale has a regenerated centre which makes it quite useless for age determination. Regenerated scales can easily be detected by the confused nature of the striations and the absence of concentric rings near the centre (Figure 21(b).

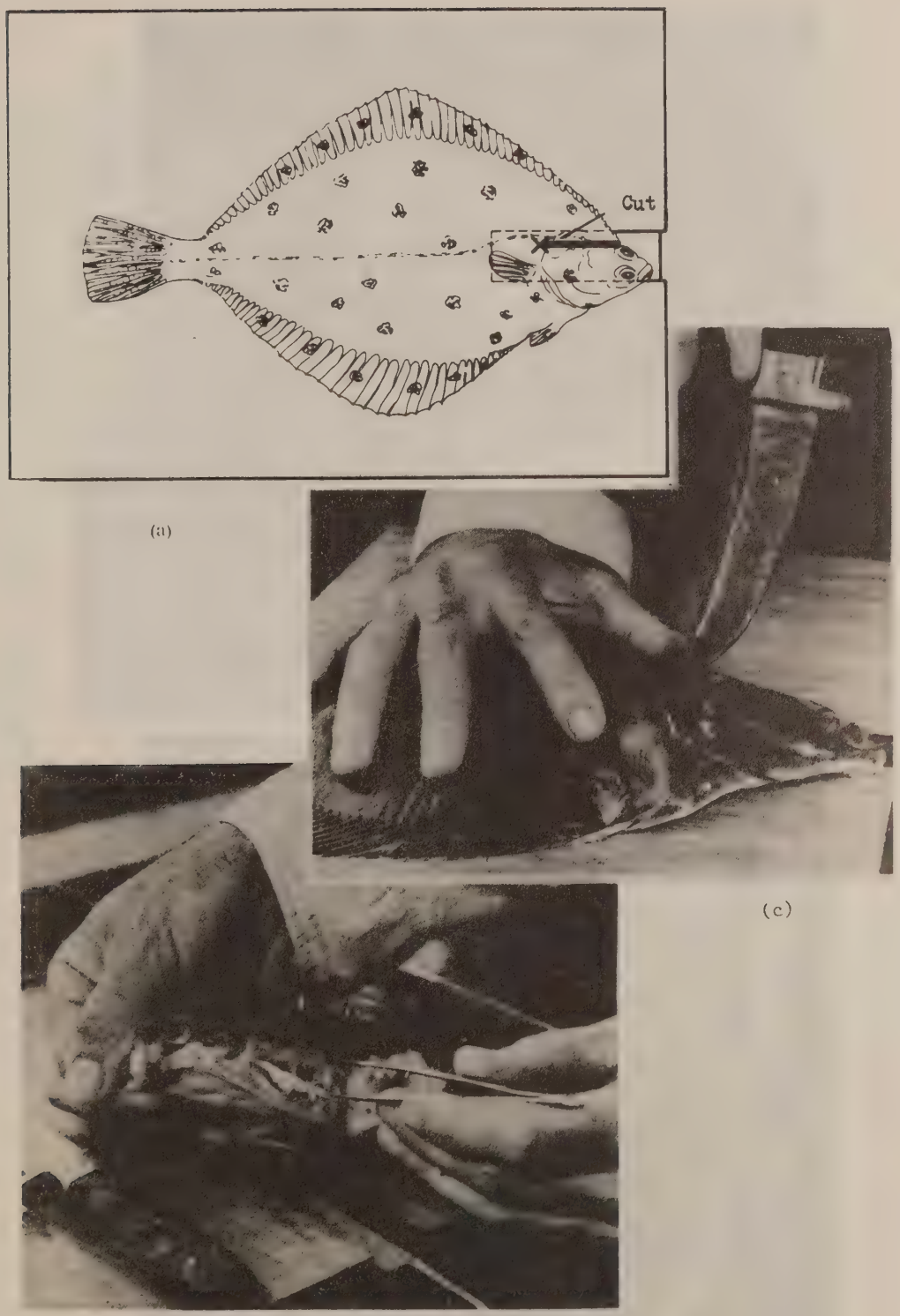
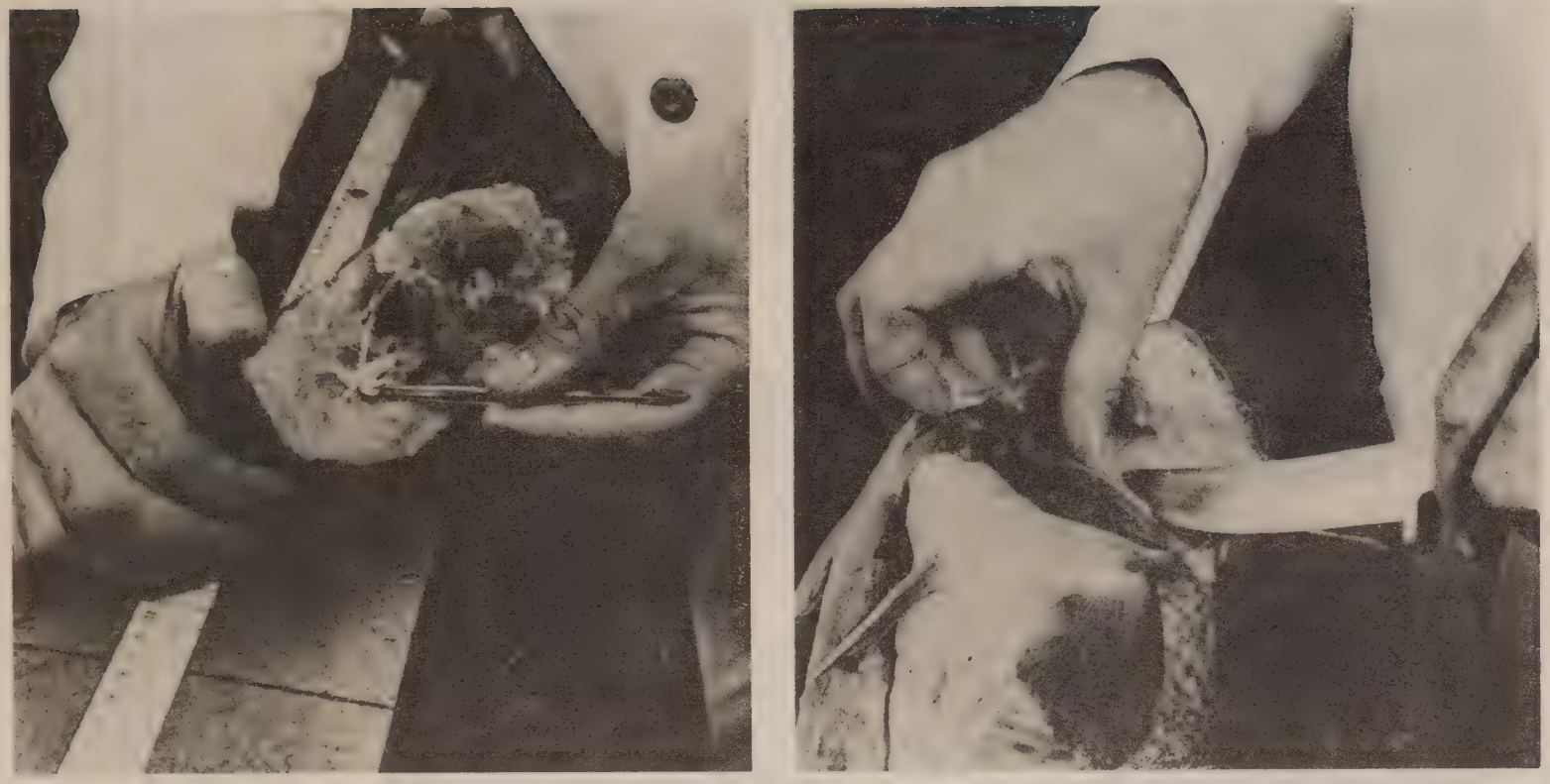


Figure 18 Removal of otoliths from flatfish

Figure 19 Removal of otoliths from roundfish



(a) (b)

Figure 20 Alternative methods of removing otoliths from roundfish
(a) by lifting off the top of the skull
(b) by extracting them from under the gills

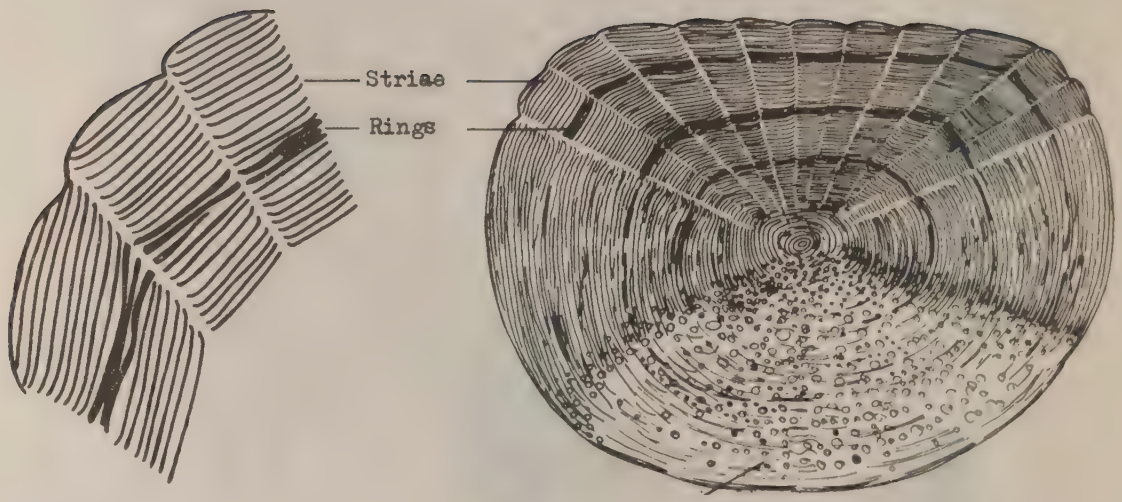


Figure 21(a) Scale of *Tilapia galilaea*

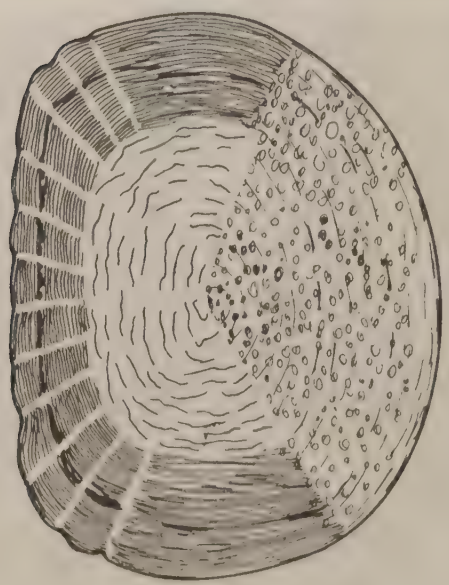


Figure 21(b) Example of a regenerated scale

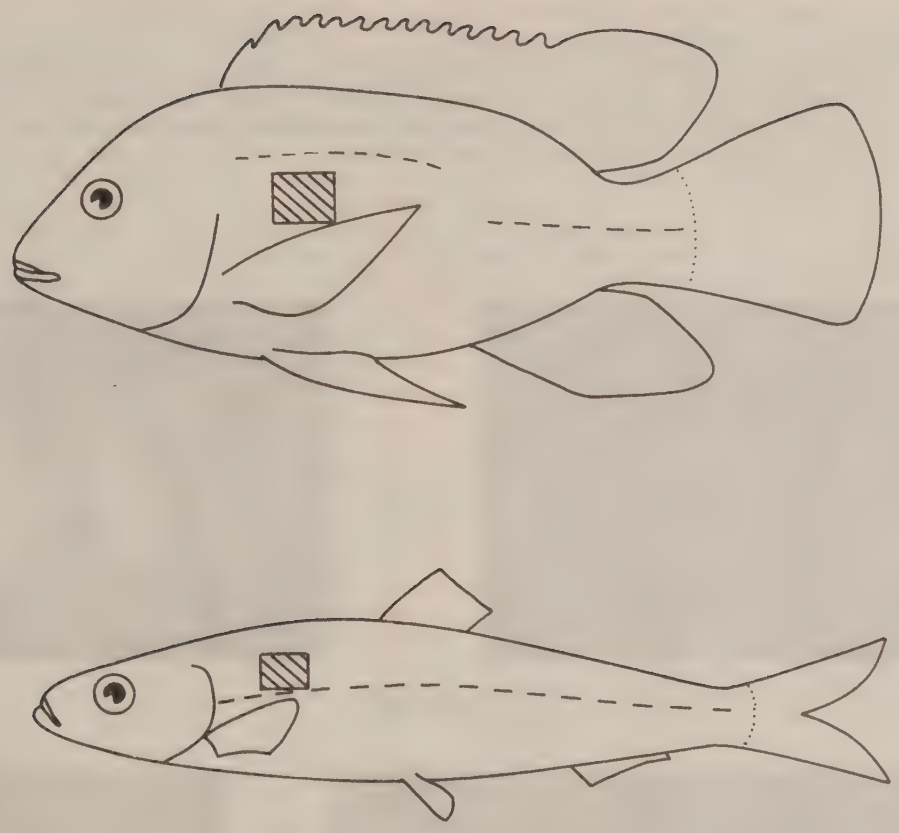


Figure 22 Hatched areas showing the best positions for taking scales for age determination

5.4 Storing and Mounting

Storage systems need to have the following advantages:

(a) Occupy the minimum space;

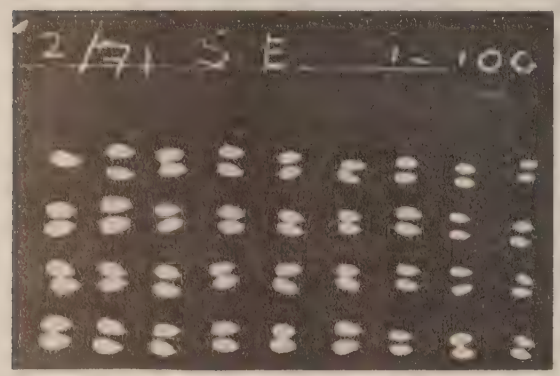
(b) Need no maintenance, such as the continuous refilling of tubes holding otoliths in a volatile liquid, and

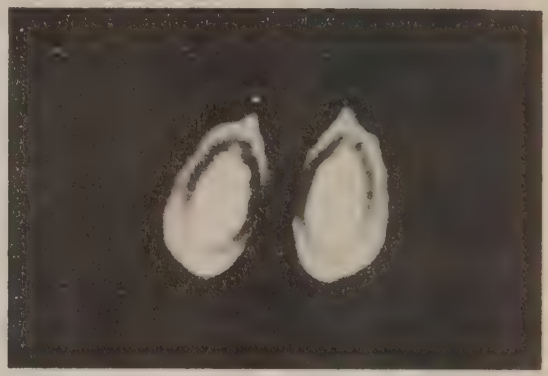
(c) Allow easy access and reference.

5.4.1 Otoliths

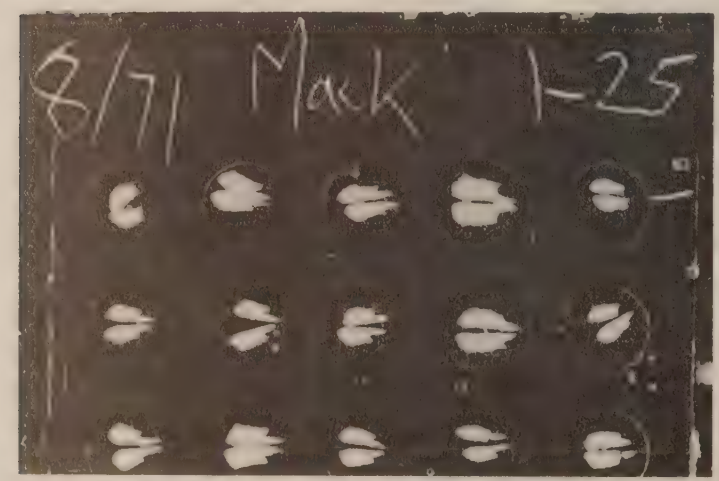
The most simple method of storage which can be used for the majority of species, is, first, to clean the otoliths thoroughly and store them dry in conveniently sized paper envelopes or plastic bags which are labelled and stacked in boxes. If it is necessary to keep the otoliths wet, then small sample tubes of the appropriate size should be used and the most suitable liquid selected. Alcohol or glycerine, an alcohol/glycerine mixture, or creosote may be used, but care should be taken to ensure that the ring structure on the otolith is not damaged or rendered unreadable by storage in an unsuitable medium. Formalin

should not be used. Whatever liquid is chosen as the storage medium, it is advisable to check regularly its effects on the appearance of the otolith. In some cases short-term storage may make the rings more easily readable, but this may be followed by a period when there is a progressive deterioration in the clarity of the ring structure. Small otoliths, such as those of sandeels or mackerel, can be conveniently handled and stored by mounting a series in resin on a microscope slide (Figure 23).





Sand eel



Mackerel

Figure 23 Storage of small otoliths by mounting them on a microscopic slide

5.4.2 Scales

Scales should be mounted on glass microscope slides, the same way up as they came off the fish, that is, convex side up. A scale is slightly curved in cross section and will curl if mounted the wrong way up on the slide. The scales may stick directly to the slide once they have dried, but in difficult cases either a spot of egg albumen, or for very thick scales, gelatine containing a fungicide or bactericide (e.g., thymol) placed under the scales will help them to stick. Large scales may be collected dry in small envelopes. When slides are used they should first be numbered in a set order so that it is possible to relate a particular scale with any other data that may be recorded from the same fish. When a slide has its predetermined number of scales on it, the scales should be levelled up one with the other. The line which divides the scale into two parts should be in a horizontal plane in the slide, with the area containing the concentric rings underneath. This will help when the scales are examined under the microscope at a later stage. It is usual to take two scales, one from each side of the fish, one to act as a check on the other (Figure 24).

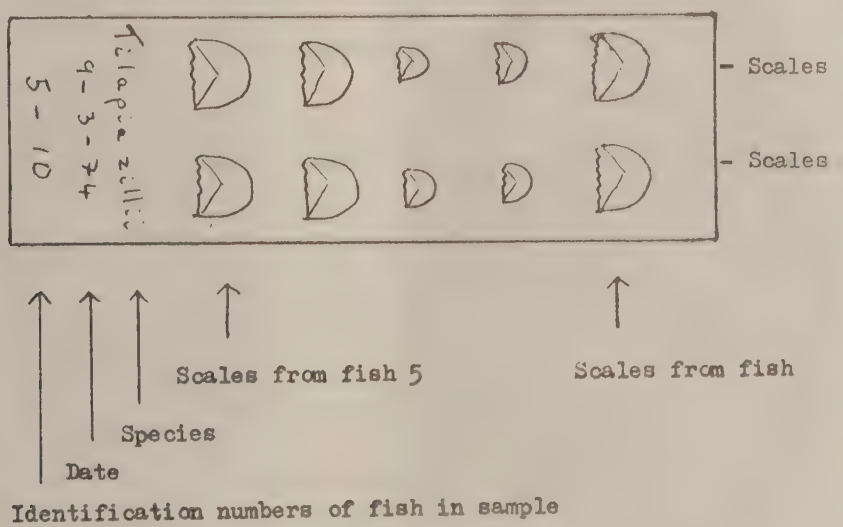


Figure 24 Method of mounting scales on a glass slide

5.5 Methods of Preparation and Viewing

Methods of viewing otoliths and scales do have some aspects in common, but since the otolith is a three-dimensional structure and the scale almost two-dimensional, the techniques used for otoliths are generally more complex than those required for scales.

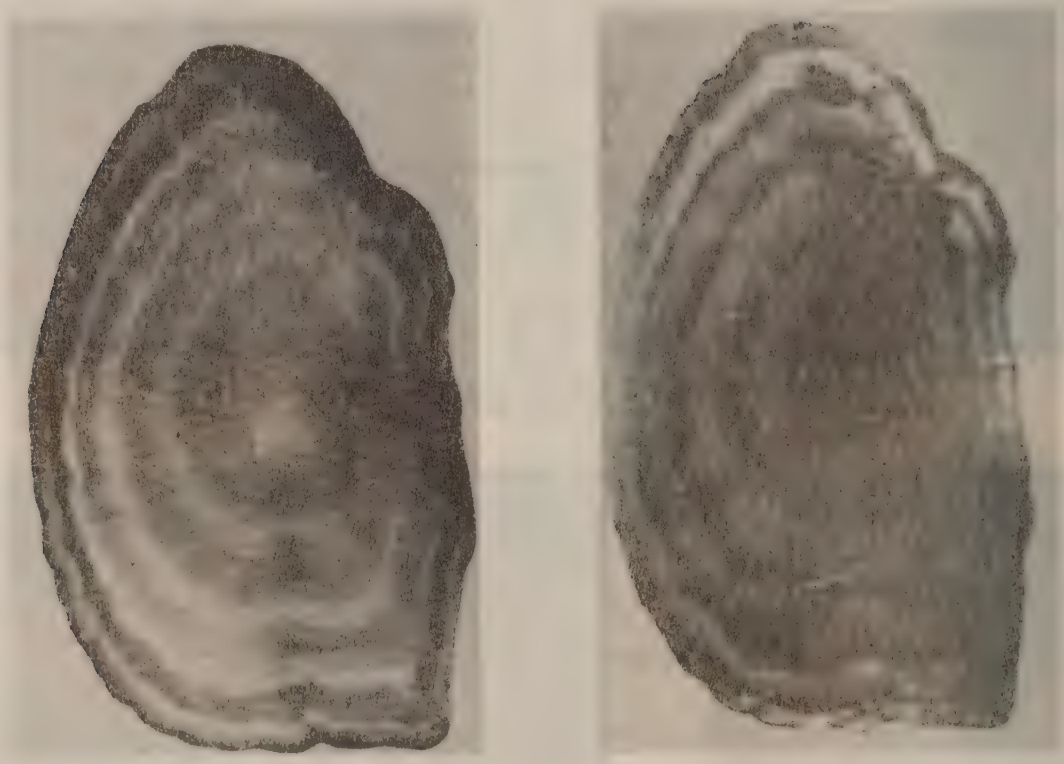
5.5.1 Otoliths

5.5.1.1 The structure of the otolith

As already stated, otoliths are three-dimensional structures but they do not necessarily grow at the same rate equally in all dimensions. If there is a pattern in the otolith it will be composed of a number of concentric shells with different radii. Depending on the amount of organic material in each shell or zone, its appearance will vary from extremely opaque to completely hyaline (transparent). There is considerable confusion in the literature over the use of these two terms. The reason for this is that the appearance of an otolith depends upon whether it is viewed by transmitted light from below or through the side, or whether it is viewed by reflected light, from above, as follows:

	Appearance	
Zone -	Opaque	Hyaline
Viewed by:		
Transmitted light	Dark	Light
Reflected light	Light	Dark

This point is illustrated in Figure 25.



Illuminated from above viewed against a dark background

(a)

Illuminated from below by transmitted light

(b)

Figure 25 An otolith viewed by two different methods

It is for this reason that the zones should never be referred to as 'light' or 'dark' zones. The term 'summer' and 'winter' zones should not be used either, because the opaque zone is not always laid down in the summer and the hyaline zone is not always laid down in the winter. The term 'annuli' should not be used for zones unless it is certain that the zones are annual. When reading otoliths it is usually preferable to identify and to count the opaque zones. If any characteristic growth patterns are visible in the otolith they will usually appear as opaque zones. In the simplest case one complete cycle of otolith growth (e.g., an annual cycle) consists in the laying down of one opaque zone and of one hyaline zone. The first zone is usually called the 'nucleus' of the otolith.

5.5.1.2 Viewing the fresh otolith

The ring structure may be most easily visible immediately the otoliths are removed from the fish. If so, then every effort should be made to read them at that time. For some species it may be the only time at which they are readable.

5.5.1.3 Viewing the whole otolith

To view an otolith a number of techniques are available. The simplest of these is to immerse the whole otolith in a clear liquid (water is quite commonly used), illuminate it from above, and view it against a dark background. This method is suitable only if the otoliths are relatively thin and translucent and all of the rings can be seen (Figure 26(a)). In many species the outer rings become very narrow once the growth rate of the fish slows down. These narrow rings sometimes are visible only on the underside of the otolith, and are completely invisible when the whole otolith is viewed from above in the manner described (Figure 26(b)). They can be seen only when a cross-section of the otolith is viewed (Figure 26(c)). When investigating any species of fish it is always necessary to check by examining a cross-section, whether these narrow rings are present before accepting an age based on viewing the whole otolith from above. Failure to understand this type of growth pattern in otoliths can result in gross underestimates of age.

It is not possible to see the narrow outer rings more clearly by grinding either surface of the whole otolith and by viewing it from above. Grinding the otolith will make it more translucent but the rings on the underside will still not be visible from above, and grinding may remove some of the rings completely (Figure 26(d)).

5.5.1.4 Preparing a cross-section of an otolith

When the structure of an otolith makes it necessary to view it in cross-section then a number of possibilities exist, either longitudinal or transverse or diagonal. All these alternatives, illustrated in Figure 27 need to be investigated before the most suitable section for routine age determination is chosen. It is frequently found that a very slight change in the angle of a cross-section will help with the interpretation of a difficult otolith.

A simple grinding machine, for making cross-sections only, enables a wide variety of otolith sections to be prepared, with the certainty that each section is across the nucleus (Figure 28). After a little practice it is quite simple to break larger otoliths at the required place with the fingers or by holding one end of the otolith firmly in a pair of forceps. If by accident the break occurs off centre, it is a simple matter to correct this by using the grinding wheel. Wetting the surface of the otolith with water or cedar wood oil applied with a fine paint brush, fills in any irregularities caused either by grinding or breaking and makes the otolith much easier to read.

Whatever method is used to prepare the otolith, it is necessary to ensure that the section is taken across the centre of the nucleus. Failure to do this can lead to a number of errors in interpretation. If the break misses the nucleus completely then the first ring will appear to be the nucleus and the age will be underestimated by one year (Figure 29(a)). If only the tip of the nucleus appears on the section then the whole appearance and spacing of the rings will be altered, making it easy to misinterpret. Possibly the true nucleus will be ignored, but certainly some confusion will result (Figure 29(b)). Only when the section passes through the centre of the nucleus will the true size of the nucleus and rings and their relationship to one another be clearly visible (Figure 29(c)).

Figure 26 Plaice otoliths: (a) a thin otolith from a young fish
(b) a thick otolith from an old fish

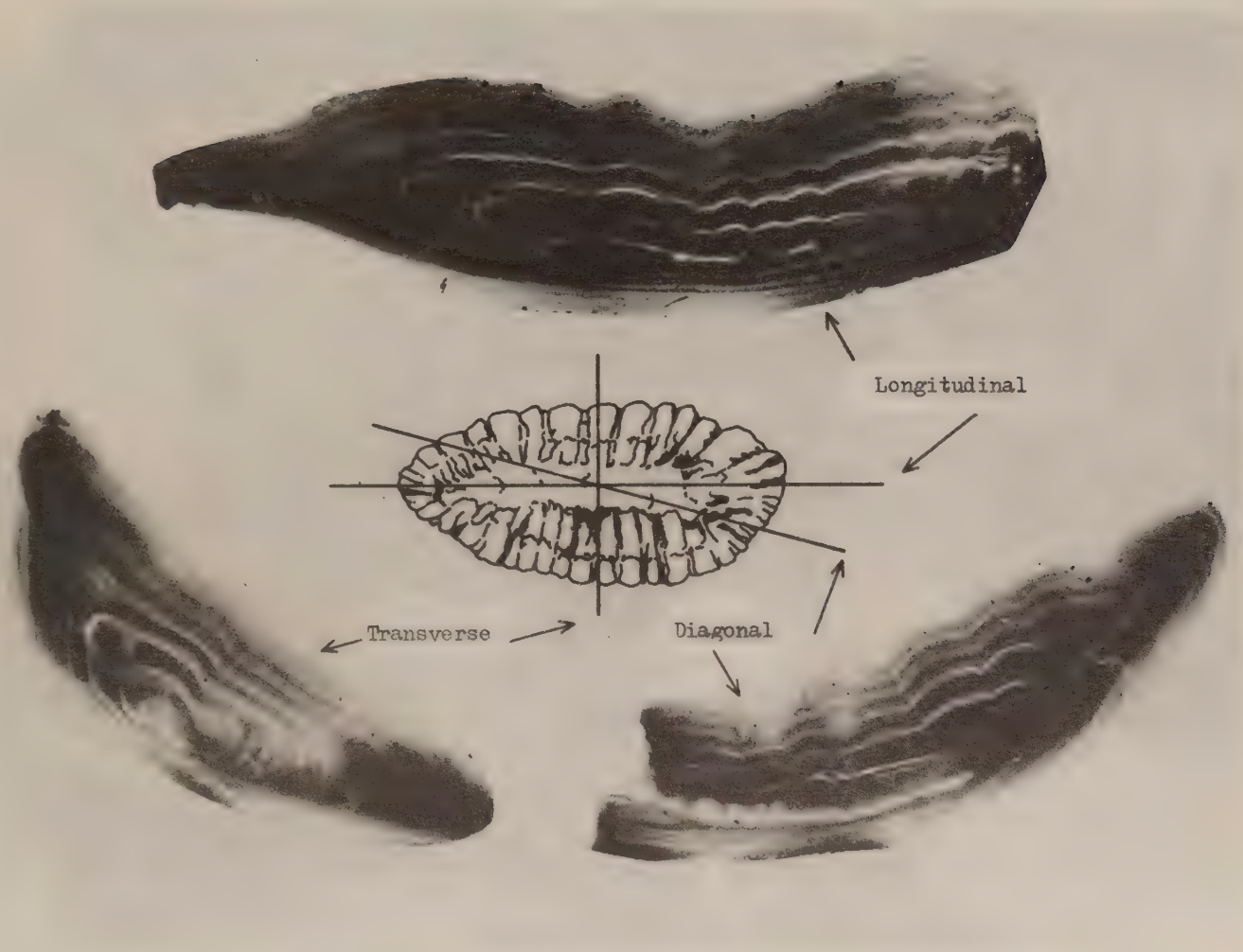


Figure 27 Different cross sections taken through a cod otolith

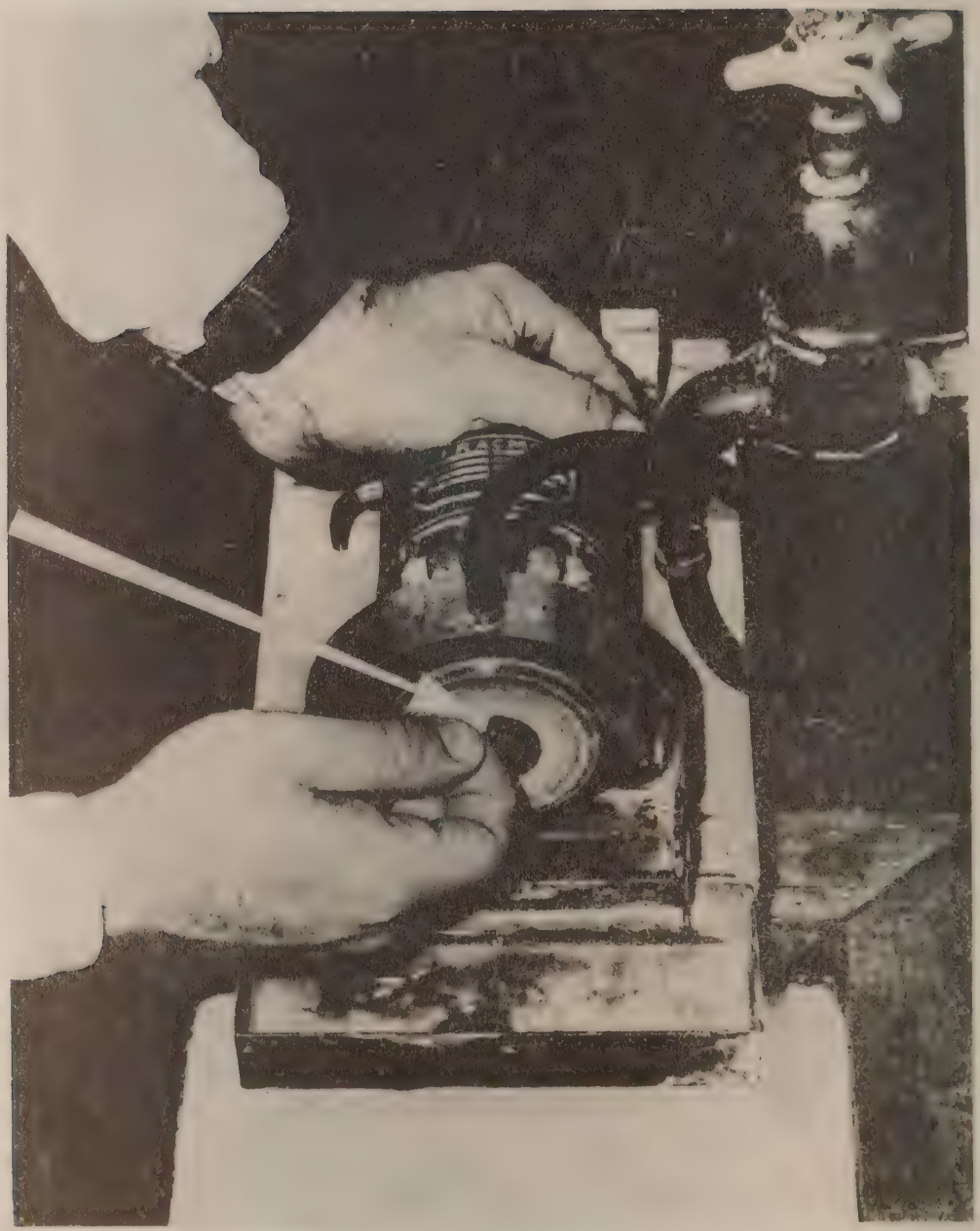
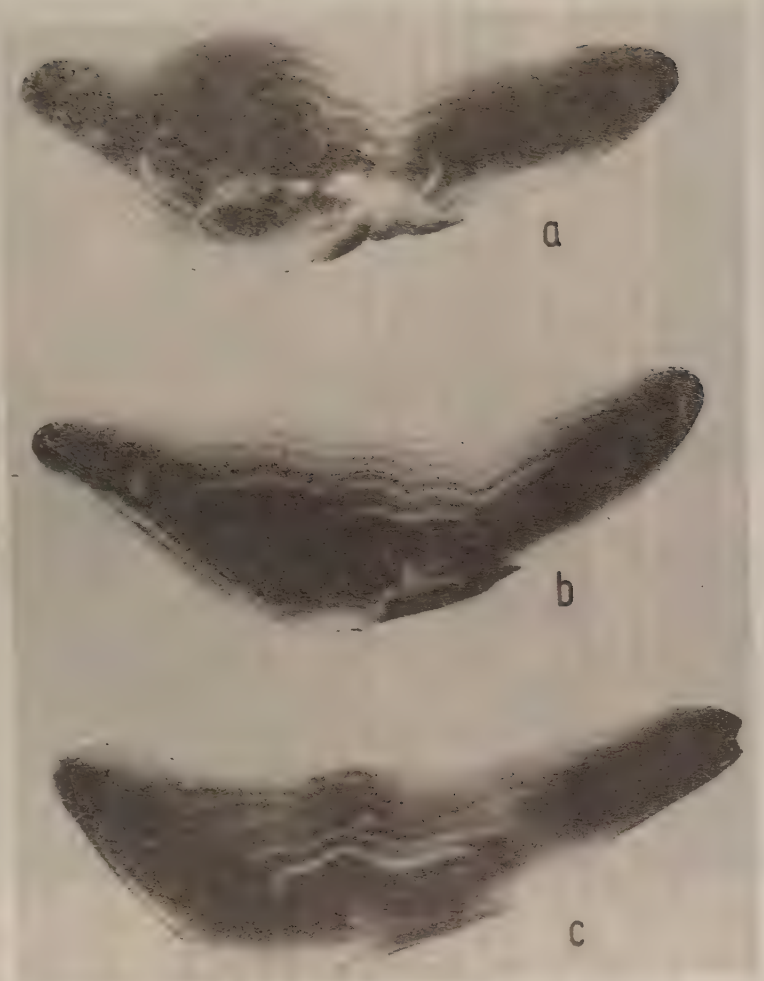


Figure 28 A grinding machine for preparing otolith sections



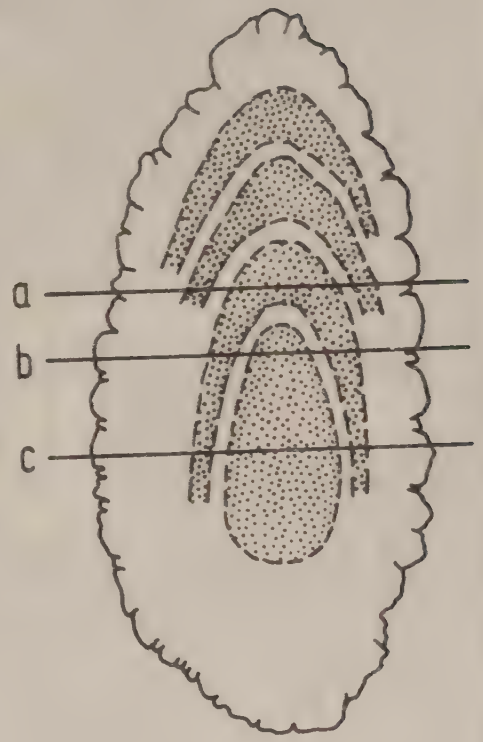


Figure 29 Three transverse sections taken at various points through the same otolith

To section an extremely small otolith, e.g., that of an eel, the otolith should be placed on a microscope slide and either covered with transparent adhesive tape or sandwiched in tape before being placed on the microscope stage. If illuminated from below, it is easy to identify the nucleus and, by pressing on it with a scalpel, to break the otolith directly across it. The tape will then prevent the very small broken halves from being scattered.

Once a satisfactory section has been prepared it can be viewed either by transmitted light or by illumination from above or after being burned (see section 5.5.1.6).

Bedford (1977) has described a technique for mounting several otoliths in black polyester resin in a mould. The mould is then mounted in a jig, which is a device for holding an object precisely in position while it is machined. Depending upon their size, several rows of otoliths are mounted in the mould with their nuclei aligned. A diamond saw is then used to cut a section through the mould, approximately 0.7 mm thick, passing through the nuclei of all the otoliths in a row. This is repeated for each row of otoliths. The thin sheets of resin containing sections of the otoliths are then mounted on large glass slides, using clear polyester resin as the adhesive, and covered with a coverslip. The slides are numbered as for scales. In this form the slides are very easy to store. Once the otoliths have been cut and mounted they are quick and easy to read.

5.5.1.5 Viewing the cross-section with transmitted light

The majority of readers of gadoid fish otoliths in Europe use the transmitted light method of illumination. The prepared section is mounted in plasticine with the surface to be viewed horizontal. The otolith is then illuminated from the side and the sectioned surface placed in shadow. This method offers considerable advantages over the method of direct illumination from above because it allows the reader to see more of the detailed structure of the otolith (Figure 30(a)).

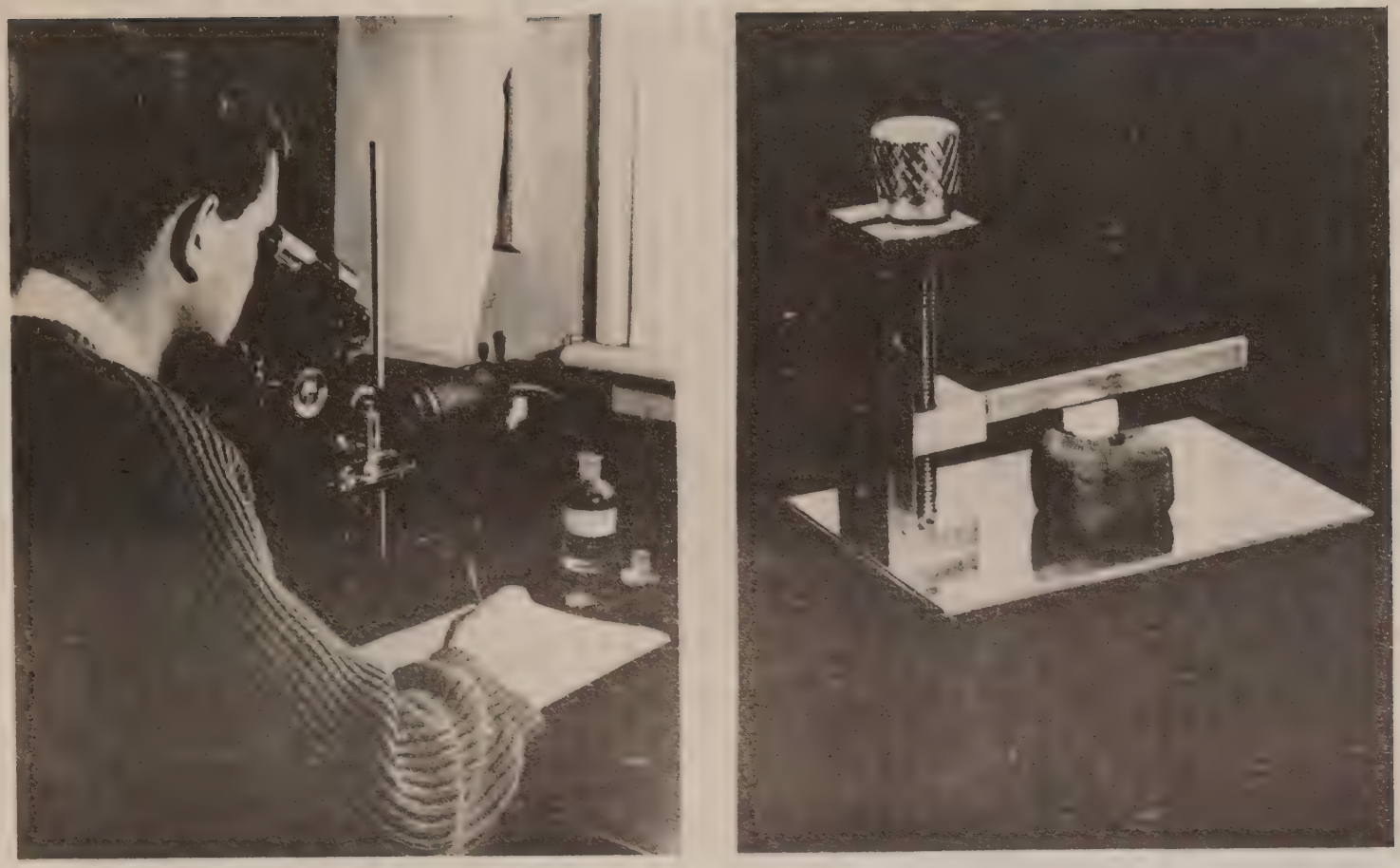
Bedford (1964) describes a simple device which allows the reader to put the surface of the section into any degree of shadow required, which may well be different for parts of the otolith. This device consists of an adjustable height bar. A brass base plate supports a vertical pillar in which is housed a captive threaded rod. By turning this thread the bar is raised or lowered to the height required (Figure 30(b)).

Scales mounted in black polyester resin (see section 5.5.1.4) are read by directing the light beam directly through the slide, as in standard microscopy. Usually low-power magnification (X5) is sufficient to allow the rings to be seen. Too high magnifications usually make age determination more difficult than easier because the overall pattern of the zones is lost. Appreciation of the overall pattern is an essential part of age determination. High magnification can be useful to discriminate between zones which are close together, as at the edge of the otoliths of old, slow growing fish.

A useful technique in reading otoliths is to attach a television camera to the microscope and to view the otolith picture on a television screen. This technique is particularly useful when otoliths with a pattern, which is very difficult, have to be read because it means that several readers can look at the otolith at the same time and discuss the various features which cause difficulty. It is also very useful when teaching people to read otoliths.

5.5.1.6 The burning technique

Rings on the otolith of some species of fish, e.g., soles (*Solea solea*), are not visible when viewed by any of the methods already described, and the narrow outer rings and split rings of other species, e.g., plaice (*Pleuronectes platessa*) and turbot (*Psetta marina*), often present considerable difficulties. If the prepared cross-section is gently burned over a very low flame of either a small Bunsen burner or a spirit lamp until it is slightly charred, then the appearance of the existing rings is altered and a narrow black ring is produced at each change from hyaline to opaque material reading outward from the nucleus of



(a) (b)

Figure 30 Method of mounting and illuminating the cross section of a cod otolith

the otolith. (Christensen, 1964.) The amount and rate of burning varies between species and the technique required to achieve the best results has to be learnt. Care must be taken to burn the whole of the sectioned surface of the otolith evenly. If the otolith is burned too much it will crumble into a grey ash; this usually occurs first at the edges of the section and it results in the complete disappearance of the ring structure. If insufficient heat is applied then the organic zones will not char. To achieve the best results the centre of the sectioned surface should be held barely touching the side of the flame and removed when it begins to turn dark brown. If after examination, it is found to require additional burning then it is a simple matter to return it to the flame until the desired result is obtained. After bieng burned, the otolith is picked up on a piece of plasticine which enables it to be moved under the microscope to any desired position. Each black ring encloses a white area representing the total growth during one year. A large number of extremely fine hair-like concentric black rings can be seen in the white zone, but the true much thicker black annual ring is clearly distinguished (Figure 31). The use of the burning technique makes it possible to age species whose otoliths were previously impossible to read and to increase the accuracy of age determination of many species, particularly those of the older fish whose age had been constantly underestimated in the past by other techniques. Problems of nucleus difficulties and false rings can often be resolved after burning. The otoliths of all species do not burn in this way.

Often a good technique is to use a combination of different viewing methods, e.g., whole otolith, illuminated from above against dark background, and sectioned burned or unburned otolith. Queries arising from one method can sometimes be resolved by using the alternative method on the second otolith of the pair.

5.5.1.7 Unusual growth zones

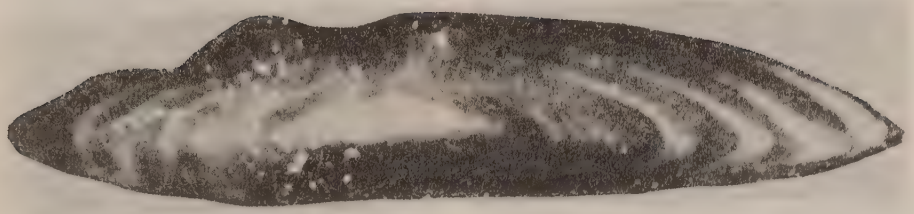
Sometimes a particular year will produce unusual growth zones. For example, the opaque zone may either be exceptionally wide or have a check in the middle or have some other unusual characteristic which is easily recognizable. The examples that have occurred in the otoliths of the North Sea plaice were found in the 1944 and 1947 year-classes. Fish from the 1944 year-class often had an extremely thin 1946 opaque zone that was easily recognized; this zone sometimes occurred in up to 20 percent of a sample of fish of the 1944 age group (Figure 32). Many of the 1947 year-class fish had a distinctive triple nucleus; this was found in 0 and 1 group fish along the Dutch coast and could be identified many years later in older fish taken from the central North Sea (Figure 33). Although these unusual zones often create difficulties of age determination when they are being formed, once the difficulties have been resolved they serve as a useful check on the validity of the age readings many years later by acting as a biological mark on the otolith. A summary of all the methods of reading otoliths is given in Table 2.

5.5.2 Scales

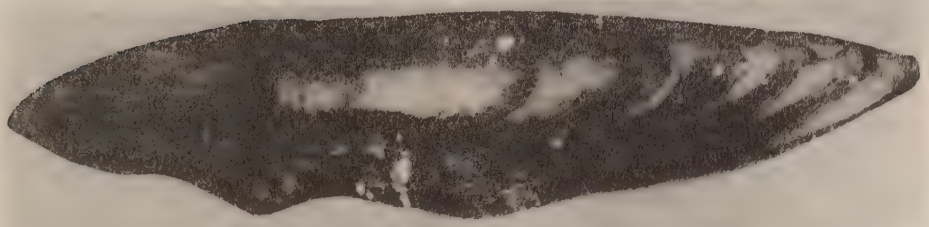
5.5.2.1 The structure of the scale

Scales are almost two-dimensional structures. The anterior part is formed of a series of sclerites which should extend in an almost completely regular pattern from the centre of the scale (Figure 21(a)). If they do not and they are confused or irregular over a very large area of the scale, then the scale is almost certainly a replacement scale, and should not be used for age determination. The structural discontinuities used for age determination result from narrow bands of irregularities in the pattern of the sclerites; the sclerites may be slightly distorted (Figure 21(a)), or they may be slightly closer spaced than the majority of the sclerites; usually the discontinuities are narrow and they are usually called 'rings'; as stated earlier the term 'annuli' should not be used because this presupposes that the rings are annual. Thus the scale presents a different picture to the otolith.

North Sea Plaice

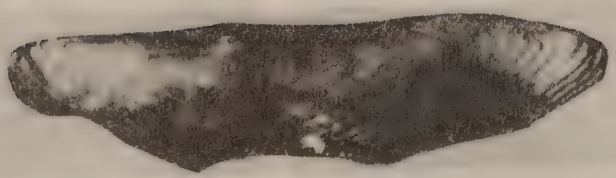


unburned cross section



after burning

North Sea Sole



after burning

Figure 31 View of cross sections of otoliths after burning

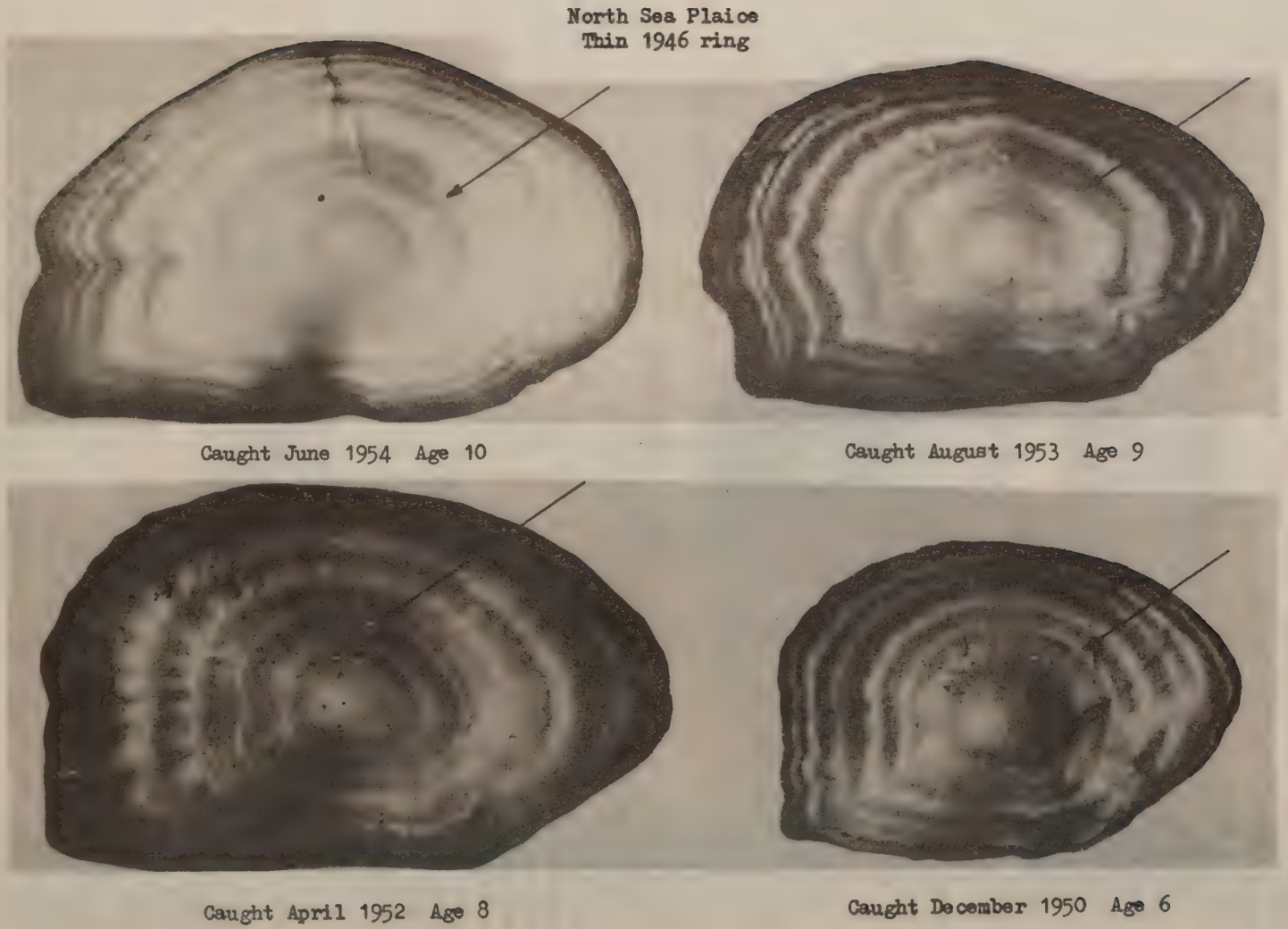


Figure 32 Examples of unusual growth zone in otolith - thin 1946 ring in North Sea plaice

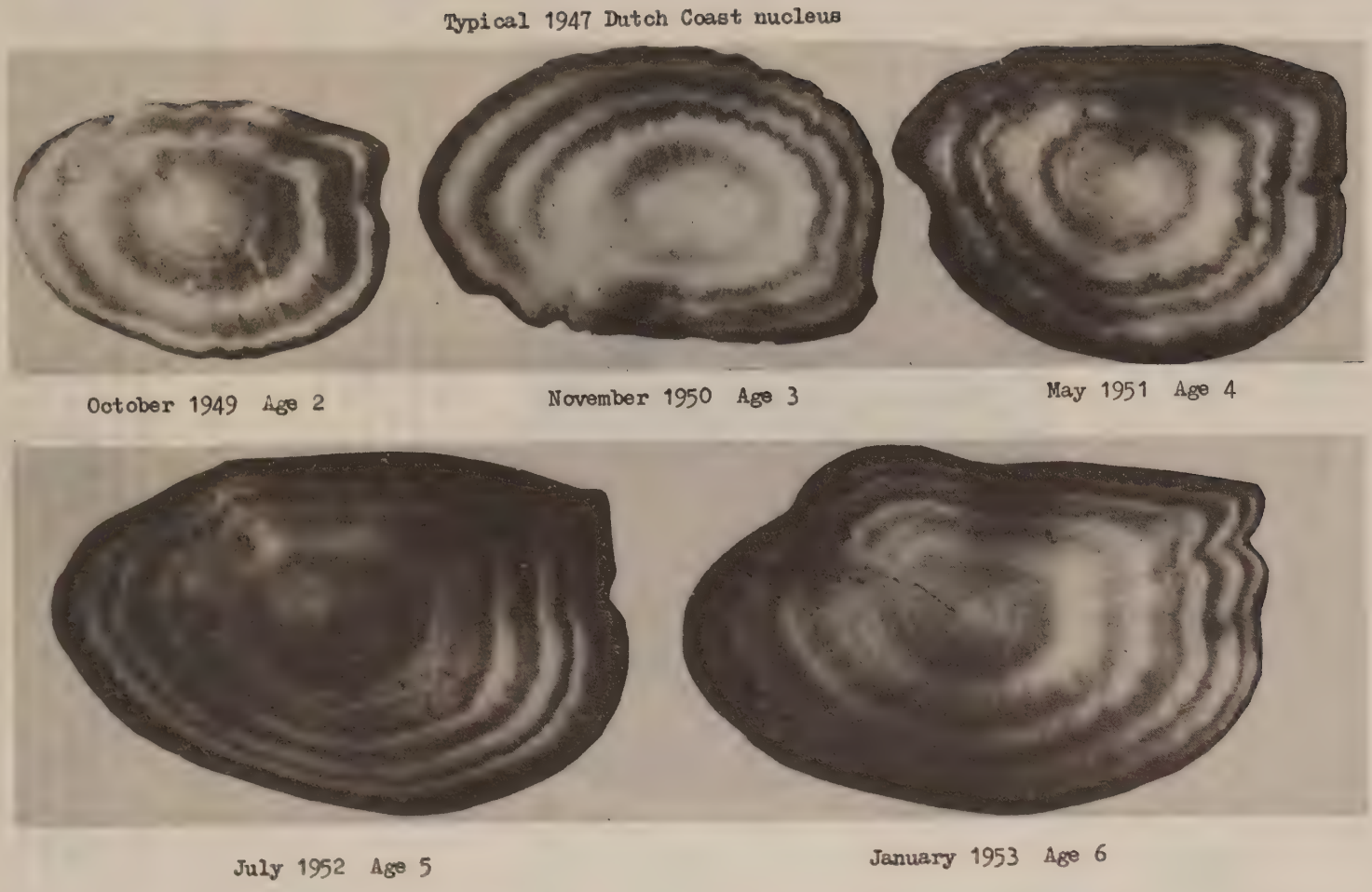


Figure 33 Examples of otoliths with distinctive triple nucleus - otoliths from 1947 year class plaice landed on Dutch coast

Table 2

Methods for Age Determination Using Otoliths
(from S. Wiedeman-Smith, 1968)

State of otolith	Treatment	Clearing liquid	Light source
whole otoliths	direct	water, alcohol xylene	transmitted or direct from above
	embedding followed by grinding	dry	direct from above
broken otoliths	direct	dry, surface is moistened with xylene, cedar wood oil	direct from above or horizontal
		water, alcohol xylene	
	after grinding	dry, surface is moistened with xylene or with cedar wood oil	direct from above or horizontal
		water, alcohol xylene	
	burning	dry, surface is moistened with xylene or with cedar wood oil	direct from above

5.5.2.2 Preparing and viewing scales

Because scales are thin structures they need no preparation before viewing but they should be cleaned before they are stored.

For reading, the slide on which the scales are mounted is placed on the stage of a low-power microscope. The mirror and condenser are removed from the microscope, and light from a lamp is reflected through the scale by means of a piece of white card or reflector. The field of the microscope should appear dark apart from a small segment at the bottom which should b very bright (Figure 34). The magnification used depends upon the size of the scale; in general, the lowest possible magnification is the best because it enables the whole scale pattern to be seen.

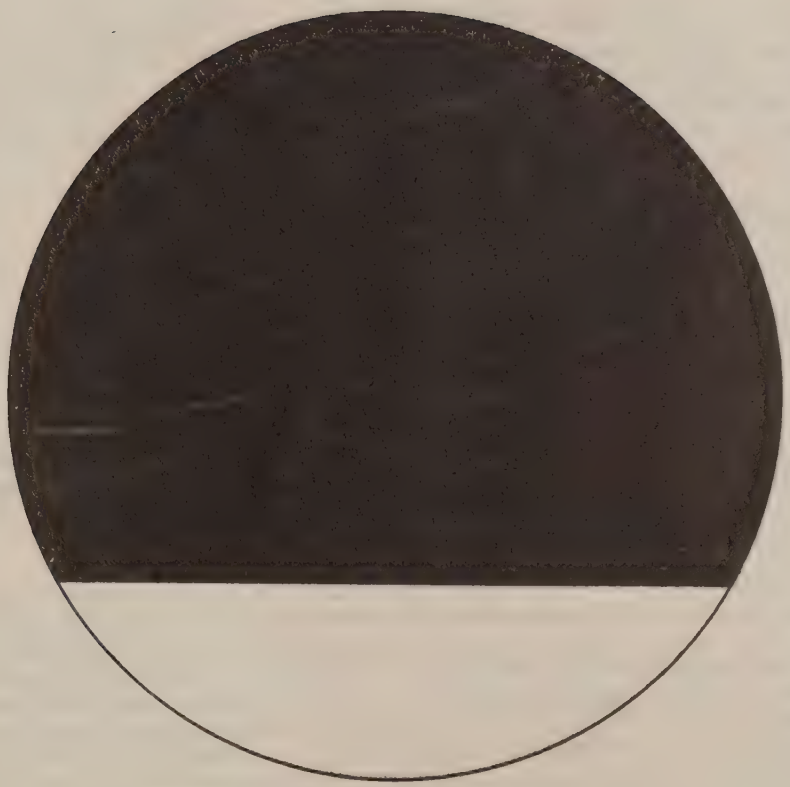


Figure 34 The lighting of the microscope field for scale examination

5.6 Other Techniques

Staining can be used to intensify structural discontinuities or to make visible those not visible by ordinary light. Galstaff (1952) describes a method of staining tuna vertebrae with alizarin but it takes up to 12 days preparation. This demonstrates the disadvantage of methods based upon staining; they are too time-consuming for processing large amounts of material, even though batch processing will allow a quicker throughput. However, if staining is the only method which will show discontinuities then it must be used, even if it does result in smaller numbers of age determinations. Polarized light and phase differentiation are also techniques that can be used.

5.7 Validation

In this section it is assumed that some pattern of structural discontinuities (for ease of reference termed 'rings' for both otoliths and scales, except when referring specifically to one of the structures) exists in the structure which is being used for age determination and that it has been made visible by some technique. The next step is to determine whether any time-scale can be allotted to the pattern of rings. This time-scale need not be annual. There are several ways in which to do this:

(a) by observing the timing of ring formation;

(b) by following a strong year-class through the fishery, and

(c) by using the Petersen method

5.7.1 Timing of ring formation

The opaque zone in the otoliths of North Atlantic species of fish is formed during the period of greatest growth and it is usually wider than the hyaline ring, particularly during the early years of the fish's life. The hyaline zone is laid down mainly during the period of slowest growth. But the timing of ring formation is considerably more complex than this simple statement suggests.

Although the opaque zone is sometimes referred to as a summer zone, the timing of its formation can vary considerably, depending upon the species of fish, where it lives and its age. In general in the northern hemisphere, the opaque zone starts to grow earliest in the southern part of the species' range and starts later with increasing distance north. Within each area the younger fish begin to lay down the opaque zone before the older fish. In the North Sea, the otoliths of a young cod may show the beginning of an opaque zone in February but an older fish may show no signs of it until June. A similar difference in the timing of opaque zone formation between young and old fish also occurs in the northeast Arctic, but the whole process is delayed by about two months; the opaque zone in the older fish may still be visible at the edge of the otolith in January of the following year. This is illustrated in Figure 35.

The type of zone forming on the edge of the otolith can be recorded from a series of samples taken throughout the year. Then, provided that the zones are annual, the growth pattern shown in Figure 36 will be observed. This series of plaice otolith photographs clearly illustrates both the timing of zone formation and the rate of growth of the otoliths during a year and there can be no doubt that the zones are annual. It should be noted that all these fish belong to the same age group (4), and have been caught during one year in the same area (central North Sea). There can be a wide variation in the timing of the formation of zones from year to year within a single species, between different areas and between fish of different age groups. All these factors must be considered when attempting to collect data to confirm the timing of zone formation. When the samples are taken from a wide range of age groups from different areas, then the seasonal difference in type of edge is not likely to be as marked. If sufficient otoliths are available, the type of edge present should be recorded separately for each age group from each area. Exactly the same techniques

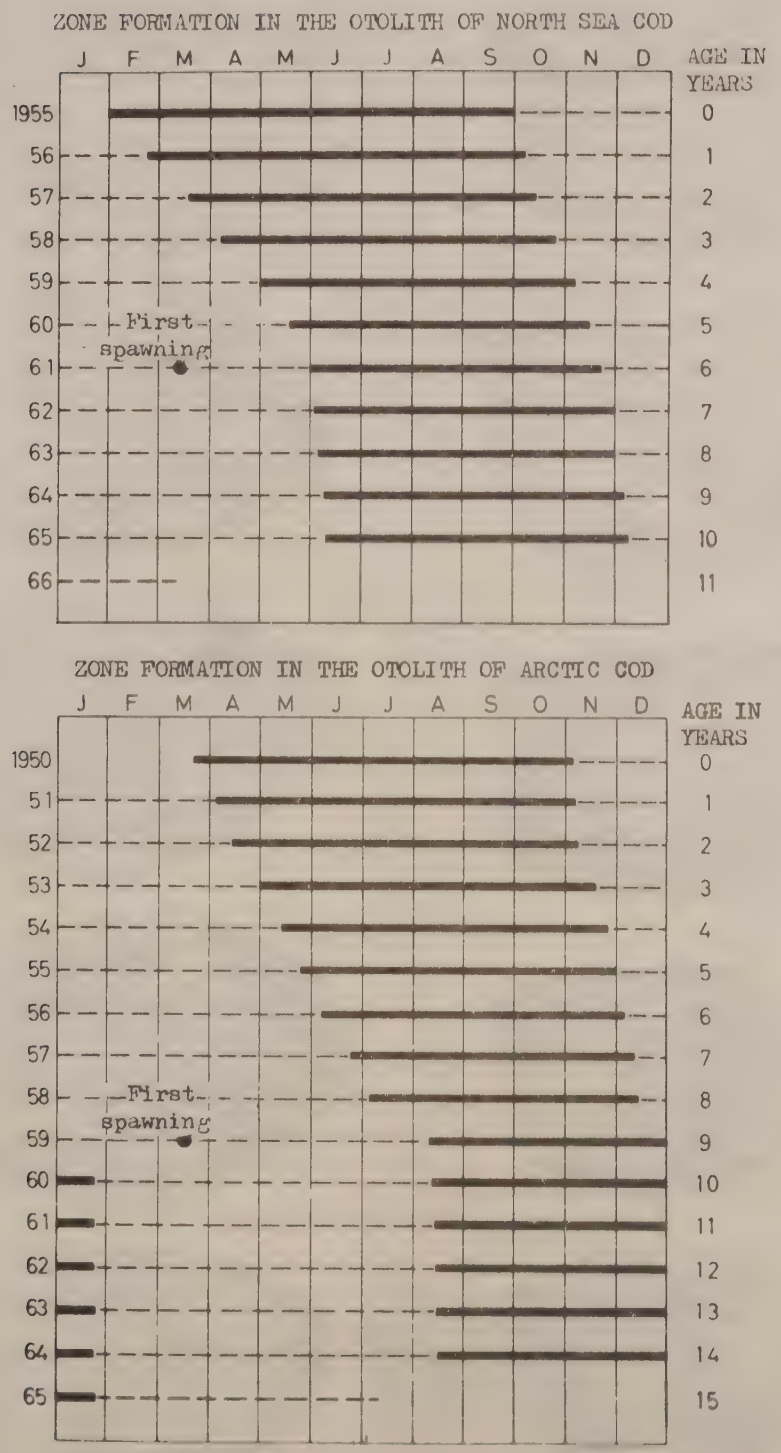
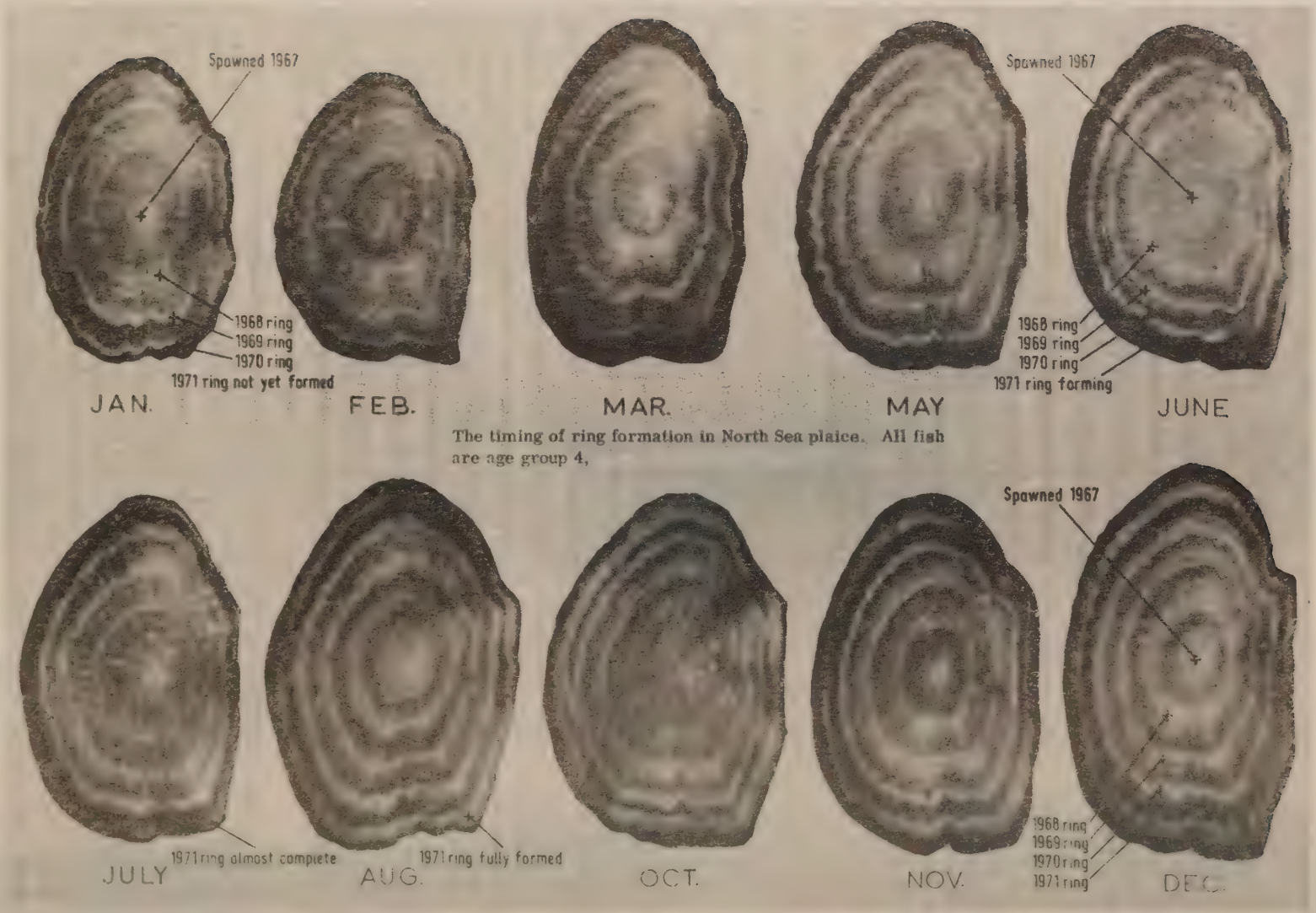


Figure 35 Zone formation of otoliths of North Sea and Arctic cod



The timing of ring formation in North Sea plaice. All fish are age group 4,

Figure 36 The timing of ring formation in North Sea plaice – all fish are of age group 4

can be used for determining the time of ring formation on scales. The change in this instance is not between one type of material and another but in the formation of the sclerites. This method can be validly used whatever the period of the time-scale over which the rings are laid down (for example, six months) as long as the sequence is regular.

5.7.2 Following a large year-class through the fishery

If a series of otolith or scale samples are available for a number of years from a stock, it is often possible to confirm the validity of age determinations by identifying a large year-class and following it through the fishery for several years. If the techniques used are sound, then a number of independent readers, each given a different year's otoliths or scales, should all produce an age composition showing the dominant year-class; this was the way in which the early North Sea sole otolith readings were confirmed. Ideally, the readers should not know that a certain year-class was large. If they do and they come across a fish whose otoliths or scales are difficult to read but which might belong to the large year-class, they will almost certainly allocate it to that year-class.

5.7.3 The Petersen method

The use of the Petersen method has already been described in section 5.1.1, for ageing fish indirectly. However, it can also be used to validate the ageing of fish whose otoliths and scales have rings. It has already been described in Section 5.1.1 how the majority of fish within a single mode in a length distribution can be allocated to an age group. If it can then be shown that the fish which have been identified as 0-group, from examination of the length frequency distribution and the time of spawning, have no rings on their otoliths or scales, and that the fish which have been identified as 1-group have one ring, etc., then it can be concluded that one ring is laid down each spawning period. More than one ring may be laid down during each spawning period. If two rings were laid down each spawning period then age determination would be validated if the 0-group fish had none or one ring on their otoliths, 1-group fish had two or three rings, etc.

5.7.4 Injection techniques

Artificial time markers can be introduced into skeletal structures by injecting chemicals into fish. The initial work was based on the use of lead acetate, but this is toxic and tetracycline is now commonly used. It has the advantage of being an antibiotic drug, stable in solid form. It is used in saline solution which must be used immediately or within 24 hours if kept in refrigeration. Tetracycline is readily absorbed by vertebrate animals and deposited in bony structures where calcification is taking place. The areas in which tetracycline is deposited in skeletal tissue fluoresce yellow in ultraviolet light, enabling them to be detected easily.

In teleost fish, which possess acellular bone, the tetracycline is laid down as a narrow ring, timing the point of injection to within a month, which is the time taken to excrete completely excess tetracycline (Figure 37). In elasmobranchs, which have partially calcified, cartilaginous, cellular bone the tetracycline is laid down diffusely throughout the skeleton present at the time of injection. Parts of the skeleton laid down subsequently contain no tetracycline.

Initial tank experiments should be carried out, if possible, to determine the optimum dose rate of tetracycline. In the field the fish have to be tagged, as well as injected, because the technique does depend upon retrieving the injected fish so that their otoliths and scales can be examined. In the North Sea the method has been used for cod and whiting (Jones and Bedford, 1968) and for rays (Holden and Vince, 1973).

WEST OF SCOTLAND COD

Illuminated by normal transmitted light

Illuminated from above by ultra-violet light

Figure 37 Otoliths of a West of Scotland cod, released after tagging and injection of tetracycline, June 1968, recaptured July 1969

5.8 Allocation of a Birthday

When it has been possible to view the rings, to count them satisfactorily and to establish that their formation conforms to a definite time-pattern, then it is possible to age the fish. In the remainder of this section it will be assumed that the fish have one spawning period a year and that the zones on its otoliths (rings on its scales) have an annual pattern of formation.

The terms age, age group and year-class are frequently used. The age of a fish at a given time refers to the period of time from birth to a given later point in time. When the age of the fish has been established, it can be assigned to the appropriate age group which is an integral number of years, according to a convention based on an arbitrarily adopted birthday. Fish said to be of a given year-class are fish born in that particular year. To simplify ageing, age determinations are usually done in terms of age groups with reference to a designated birthday. This birthday does not have to coincide with the biological time of birth. For convenience, there is a convention to use 1 January for most Atlantic species, even though the time of spawning of some species may be in the December of the previous year, and other species may not finish spawning until May. This system of identifying fish by age groups is shown schematically in Figure 38 and by photographs of a set of North Sea plaice otoliths in Figure 36. In the latter figure the fish of age group 4 have four opaque and four hyaline zones in January 1971. By June 1971 the fifth opaque zone is visible but it does not become a 5-group fish until 1 January 1972. For the whole period, 1 January 1971 to 31 December 1971 it is a 4-group fish. Its true age on 1 January 1971 would be 4 years exactly (assuming it was spawned on 1 January 1967) and on 31 December 1971, 4 years, 11 months, 30 days.

The great advantage of this method is that it enables the year-class of a fish to be established immediately by subtracting age group from year of capture (in the above example 1971 - 4 = 1967) and it permits easy grouping of data collected by different laboratories. The method does require a good knowledge of the pattern of zone ring-formation because it may be necessary to discount zones or rings that have already formed (the fifth opaque and hyaline zones in the plaice shown in Figure 36 from June to 31 December), or to assume that a zone or ring should have been formed but is not yet visible. This is shown in Figure 35; the opaque zone of a 15 year old Arctic cod is not visible until January of the year after which it is laid down; that is, the 1973 opaque zone is not visible until January 1974. In November and December 1973 it is necessary to take this into account and not count the visible hyaline edge as the edge now forming in the 1973-74 winter.

Problems arise if the fish spawn near to the time of the event which causes the rings. Some stocks of North Sea herring spawn in the autumn, and their larvae are insufficiently developed for rings to form on either their scales or otoliths during their first winter. The first ring is not laid down until the fish are in their second winter, when they are approximately 15 months old. It is customary to refer to fish spawned in, say, 1976 and caught in 1978 as "1-ring" fish (or sometimes "1-ringers"), 1976 year-class.

Counting the rings present on the scales or otoliths and calling the fish only "3-ring fish", or "4-ring fish" without making any allowance for the time at which the rings are laid down, should not be done under any circumstances. Take, for example, a species which spawns in March and which forms rings on its scales in December-January. If only rings are recorded, it would not be known if a fish which was caught in the period December 1978 - January 1979 and which was called a 3-ring fish had just laid down a ring and therefore belonged to the 1976 year-class or was just about to lay down a ring and therefore belonged to the 1975 year class.

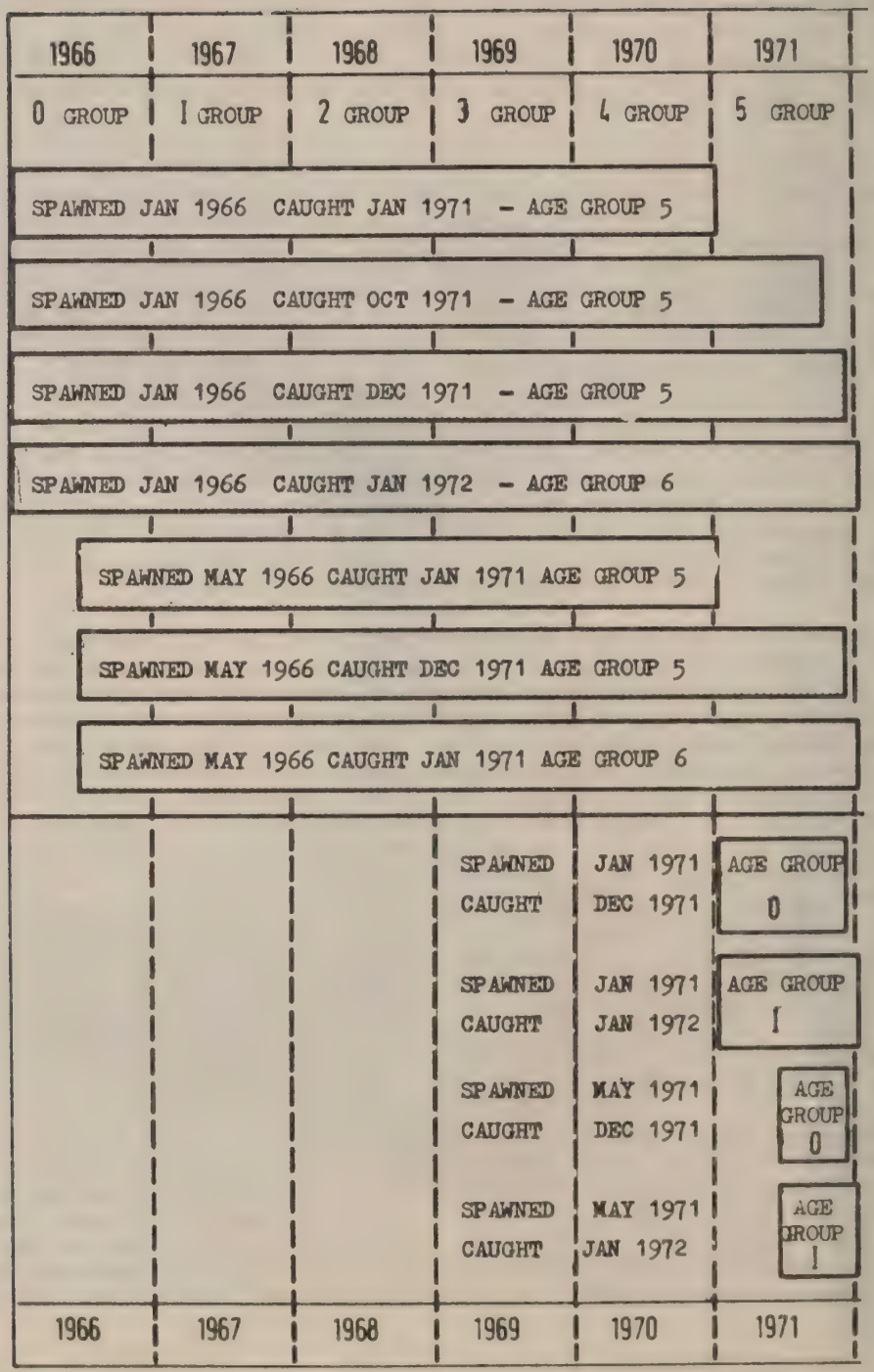


Figure 38 Schematic system of identifying fish by age groups

5.9 Special Uses for Otoliths and Scales

5.9.1 Spawning zones

Some species exhibit a different ring structure after the onset of spawning. In Arctic cod the post-spawning opaque zones are extremely narrow and regular. These post-spawning zones can be identified, counted and the otoliths used to provide data on the number of times each fish has spawned, in addition to giving the age (Rollefsen, 1933) (Figure 39).

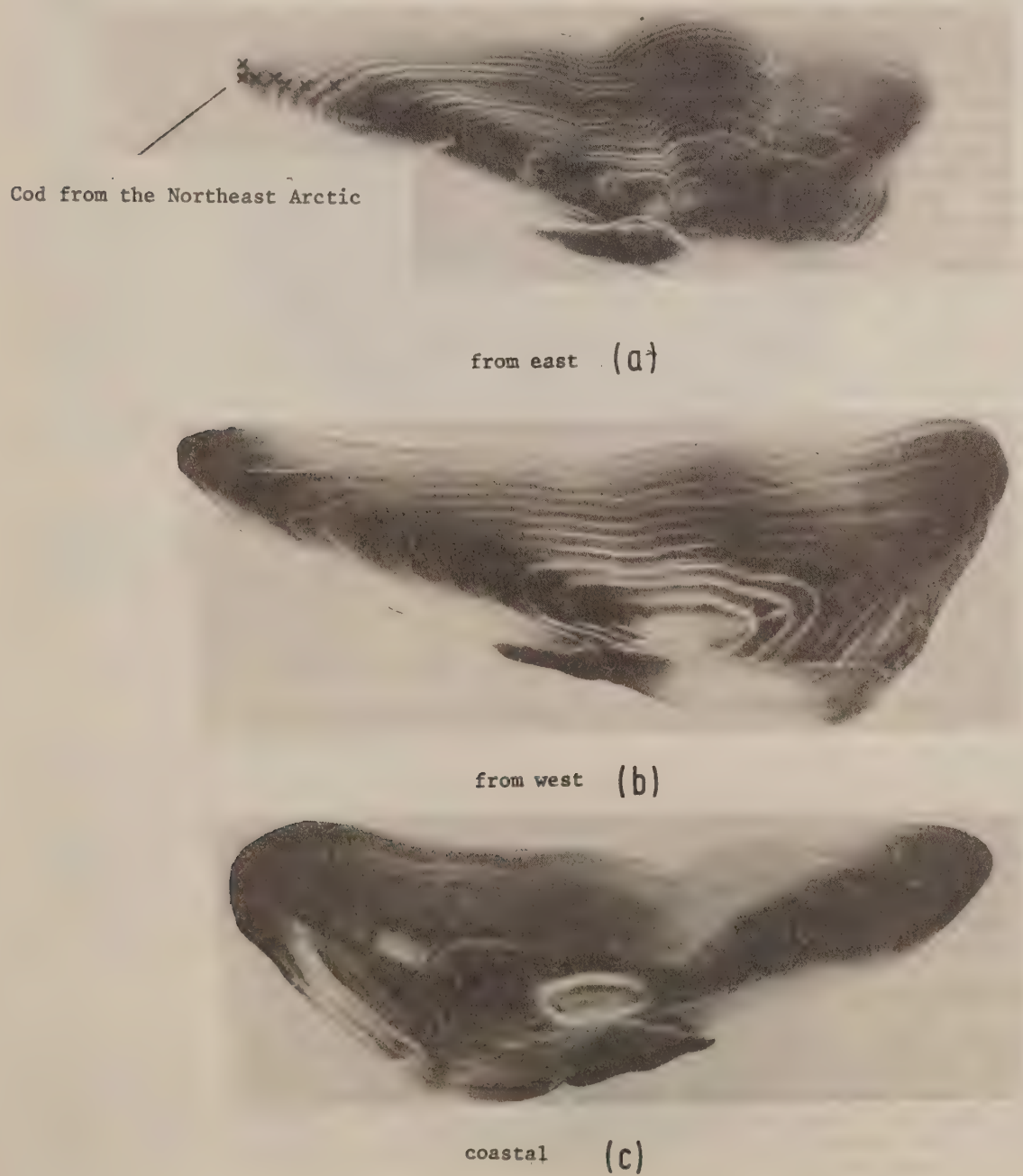


Figure 39 Typical northeast Arctic cod otolith types

One feature that can be observed on the otoliths of mature cod is the wider and brighter hyaline zones that sometimes occur immediately before the first post-spawning opaque zones.

5.9.2 Stock patterns

Otoliths can be used for identifying unit stocks. The pattern of the zones which appear within the otolith reflect the conditions under which the fish have grown. Fish which have been spawned together and which have lived in the same area are likely to have very similar patterns within their otoliths. Such fish will also, by definition, belong to the same unit stock. Their otoliths will have different patterns from those of other fish of the same species which have been spawned elsewhere and have lived in different areas and which therefore will be of a different unit stock. However, fish of the same species but from different unit stocks can occupy the same area and can therefore have similar patterns on their otoliths. Therefore, if there is no difference in the otolith patterns between fish it is no evidence that the fish necessarily belong to the same unit stock. If different otolith patterns are found then it is evidence that the fish may belong to different unit stocks. This is not conclusive evidence because different fish of the same unit stock may inhabit different areas and in consequence have different otolith patterns. Additional evidence, such as from tagging, is needed to determine whether the otolith pattern is diagnostic of a unit stock. For example, three distinctive otolith patterns appear in cod otoliths caught off the northeast Arctic off northern Norway. These are shown in Figure 39. Tagging has shown that both the cod caught in the eastern and western Barents Sea belong to the same unit stock, the Arcto-Norwegian cod stock. Therefore, the difference between otoliths of type (a) and type (b) is not diagnostic of a unit stock difference but only shows that the growth pattern in different parts of the area inhabited by the unit stock are different. On the other hand, type (c) is diagnostic of the local coastal cod which tagging has shown is a separate unit stock from the Arcto-Norwegian stock. The main diagnostic feature is the very bright hyaline zone around the nucleus of coastal cod.

Differences in the size of growth zones on scales (distance between two rings), particularly the first growth zone, are used to separate stocks of North Sea herring. Also the country of origin of North Atlantic salmon can be determined by the number of growth zones laid down while they are in fresh water during the early part of their life when the growth rate is much slower than in the sea.

5.10 Some Difficulties and Possible Sources of Error

5.10.1 Differences between otoliths from the same fish

There can be differences in the number of rings present in the two otoliths taken from the same fish. Fortunately this is an extremely rare occurrence and can usually be detected by a fairly superficial examination of both otoliths, when a deformity in the shape or structure of one or both otoliths is easily visible. Scales rarely differ unless one is a regenerated scale, as shown in Figure 21(b). However, scales from some parts of the body are much easier to read than others, as described in section 5.3.2. If scales are used for back calculation of the lengths at which the rings were laid down (see section 5.12) it is essential that they are all taken from the same part of each fish. Scales taken from different parts give different results.

5.10.2 Variation of age at length

It is not at all uncommon for the growth rates of the same species of fish taken from the same area to show an extremely wide variation. For example, small North Sea plaice in the 25-29 cm length range can be from 1 to 7 group, the 1 group being most likely to occur in December when their actual age is 1 year and 11 months old. The 30-34 cm length range could contain fish between 2 and 12 years old, and among the fish in the 45-49 cm length range, the age could lie between 7 and more than 20 years.

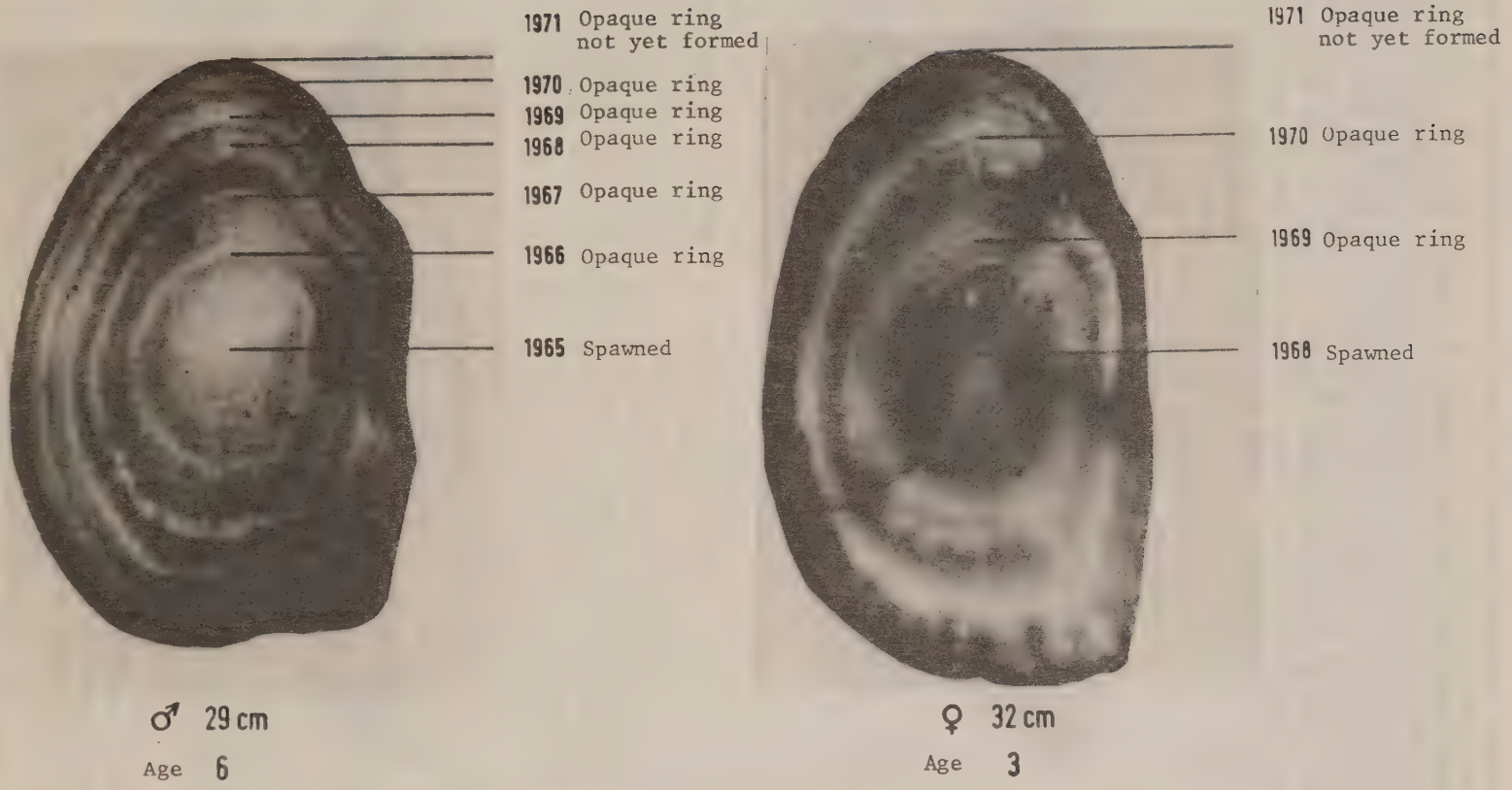
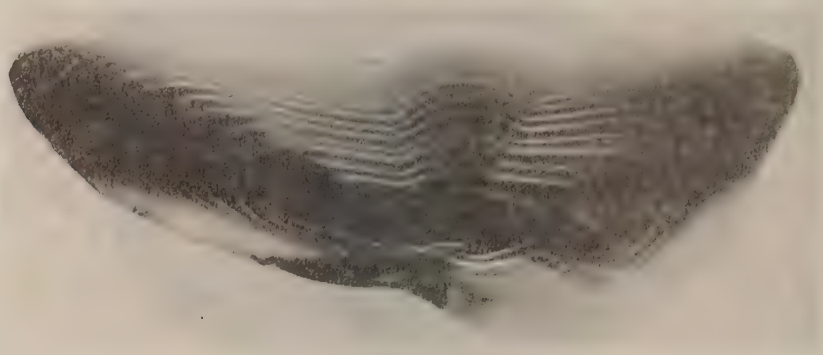


Figure 40 Plaice otolith from slow and fast growing fish of same size

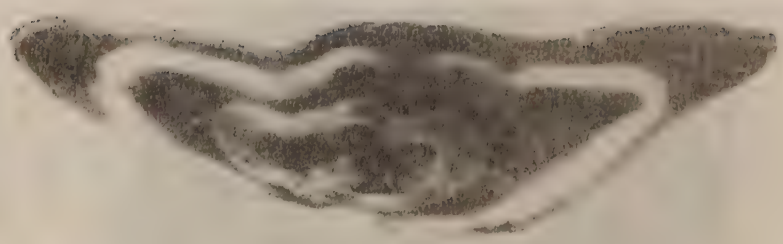
Wide variations in growth rates also occur in other species and great care should be taken not to fall into the error of first looking at the length of the fish from which the otoliths have been taken, deciding what the age is likely to be, and then looking at the otolith or scale and attempting to make the preconceived age fit the visible structure, either by grouping or omitting rings. A similar error is to attempt to define size limits within which the nucleus or zones must fall, based on the size of zones found on other otoliths. A slow-growing fish may have three or four annual zones occupying the same space as one or two zones on a fast-growing fish (Figures 40 and 41). It is therefore impossible to say that some zones must be false because three or four narrow annual zones occupy the space of one very wide annual zone. These comments apply also to scales.

Cod



length 67 cm age: 17 years

North Sea Cod



length 67 cm age: 3 years

Figure 41 Two cod otoliths from fish of the same size but widely differing age

5.10.3 False rings and check zones

The main source of difficulty in otolith reading is to distinguish as certainly as possible the true annual zones from secondary, false, split or check zones. If the otolith burns satisfactorily this usually clears up any queries. It is usually assumed that any ring on a scale which runs round the whole of the anterior edge is a 'true ring', and is counted and that one which does not do this is a 'false ring' and is not counted. Solutions to these problems can be gained only by study of the species under investigation.

Age determination is a skill which has to be learnt. Some people become more proficient at it than others; some never become competent. While the European Inland Fisheries Advisory Commission (EIFAC) is preparing a scale atlas based on fish of known age, the whole purpose of reading scales and otoliths is to determine the age of fish whose age is unknown and whose absolute age will always be uncertain. The best reader in the world cannot state with 100 percent certainty the exact age of a wild fish.

To avoid errors and systematic bias, frequent cross-checking of results between readers and by the same reader repeating the reading of a sample at a later date will ensure that no wide differences of interpretation occur and that the readings remain consistent. Readers must always be objective.

5.11 Causes of Zone and Ring Formation

Any major change in the environment in which a fish lives is likely to produce ring formation (in this sub-section ring and zone formation will be considered synonymous). In the earth's temperate zones differences between summer and winter are marked by both changes in water temperature and amounts of food available. It is these very regular and very marked changes which make the age determinations of most temperate fish species so easy. But equally marked changes occur within the tropics. Many rivers in the tropics are subject to seasonal floods. During the floods, food is abundant and the fish grow rapidly. In the dry season food becomes very scarce and the fish often starve. This results in very marked rings forming on the scales. Examples are the Gambia (Svensson, 1933) and the middle Niger (Daget, 1956). In Lake Chad, Hopson (1965) has described how the fall in temperature in November-January causes the formation of rings on the scales of *Lates niloticus*. Poinsard and Troadec (1966) describe the age determination of *Pseudotolithus senagalensis* and *P. typus*, two West African marine species, both of which lay down an opaque zone during the warm season and a hyaline zone in the cold season. As there are two warm and two cold seasons each year, these species lay down two opaque and two hyaline zones each year on their otoliths.

Garrod (1959) aged *Tilapia esculenta* in Lake Victoria by proving that the rings which occur at the edge of the scale were laid down at spawning. A time-scale was allotted to the rings by then proving that this species spawned twice a year in the north of Lake Victoria and once a year in the south. Seshappa (1969) describes a similar study to that of Garrod, using the rings caused by spawning that form on the scales of Indian mackerel, *Rastrelliger kanagurta*. Seshappa also examined the otoliths of this species but found no zones on them.

When faced with the age determination of a new species the first question must be "Has it got rings on its scales or zones on its otoliths which can be read by some method?". The second question must be "What causes these rings or zones so that a time-scale can be set to them?". The regularity of the event causing ring formation must be checked to determine that no other events will lay down rings similar to the main seasonal rings. This is most likely to happen if the species being studied is living in a small volume of water, such as a small lake or pond. In temperate zones the main rings may be caused by summer-winter variations in the environment but other events may produce rings identical to annual ones. These events might be either plankton blooms or sudden unseasonal changes in temperature or accidental discharge of pollutants, to quote three possible examples.

6. DETERMINATION OF GROWTH PATTERNS OF INDIVIDUAL FISH FROM SCALES AND OTOLITHS

The use of scales and otoliths for determining the age of fish has been discussed. Just as counting rings on scales and otoliths of fish gives age of fish, position of rings in scales and otoliths can provide size of fish at each preceding age, i.e., at the time each ring was laid down, provided there is some relation between body length of fish and the dimension of fish scale. This is, indeed, another use of scale and otolith readings and is known as the method of back calculation of body lengths of fish.

6.1 Types of Relation Between Fish Size and Scale Size

Three types of relation are in common use. They assume:

(a) Isometric growth. In this case the relation between body length l of fish and the length of scale radius r is assumed to be $l = br$, where b is a constant proportionality;

(b) Linear allometric growth. In this case, a linear relation $l = a + br$, is assumed between l and r, and

(c) Curvilinear allometric growth. In this case, a non-linear relation between l and r is assumed.

6.1.1 Isometric growth formula

Early fishery workers assumed that a direct proportion relation existed between scale and body length-growth throughout the life of the fish. The basis for this assumption came from the general knowledge that although fish may vary in size they possess approximately the same body contour, that the scale counts of small and large fish are similar, and that the outlines of the scales in both small and large fish are approximately the same.

The formula for the back calculation of body lengths on the assumption of direct proportion between scale and body growth is:

$$\frac{\text{length of scale radius to } i^{th} \text{ ring } (r_i)}{\text{length of total scale radius } (r)} = \frac{\text{length of fish when } i^{th} \text{ ring was formed } (l_i)}{\text{length of fish when scale sample was obtained } (l)}$$

$$\text{i.e., } l_i = \frac{r_i}{r} l$$

The values of l_i's can be easily calculated by using a simple proportion board (Figure 42). This consists of a graduated rule fixed to the right-hand side of a polished board at right angles to the bottom edge which is lipped. An ungraduated rule, pivoted at the bottom left-hand corner of the board and long enough to overlap the top right-hand corner, completes the device. To use the board an image of a scale is projected onto a rectangular piece of white card. The bottom end of one edge of the card is placed on the nucleus of the projected scale, and the positions of the rings and the edge of the scale are marked on the edge of the card at an angle of 90° to the baseline. The marked card is then positioned on the board with the edge of the card which corresponds to the nucleus, flush with the lip at the bottom of the board. The lower edge of the diagonal, ungraduated scale is then placed at that length on the graduated rule at the right-hand edge of the board which corresponds to the length of the fish. The card is then moved along so that the line which marks the edge of the scale is directly under the lower edge of the ungraduated rule. This rule is then pivoted and placed directly over each of the marks on the card and the appropriate length is read each time from the graduated rule on the right. Griffiths (1968) describes a more sophisticated electronic proportion device which automatically presents the growth data on the scale of a digital Voltmeter.

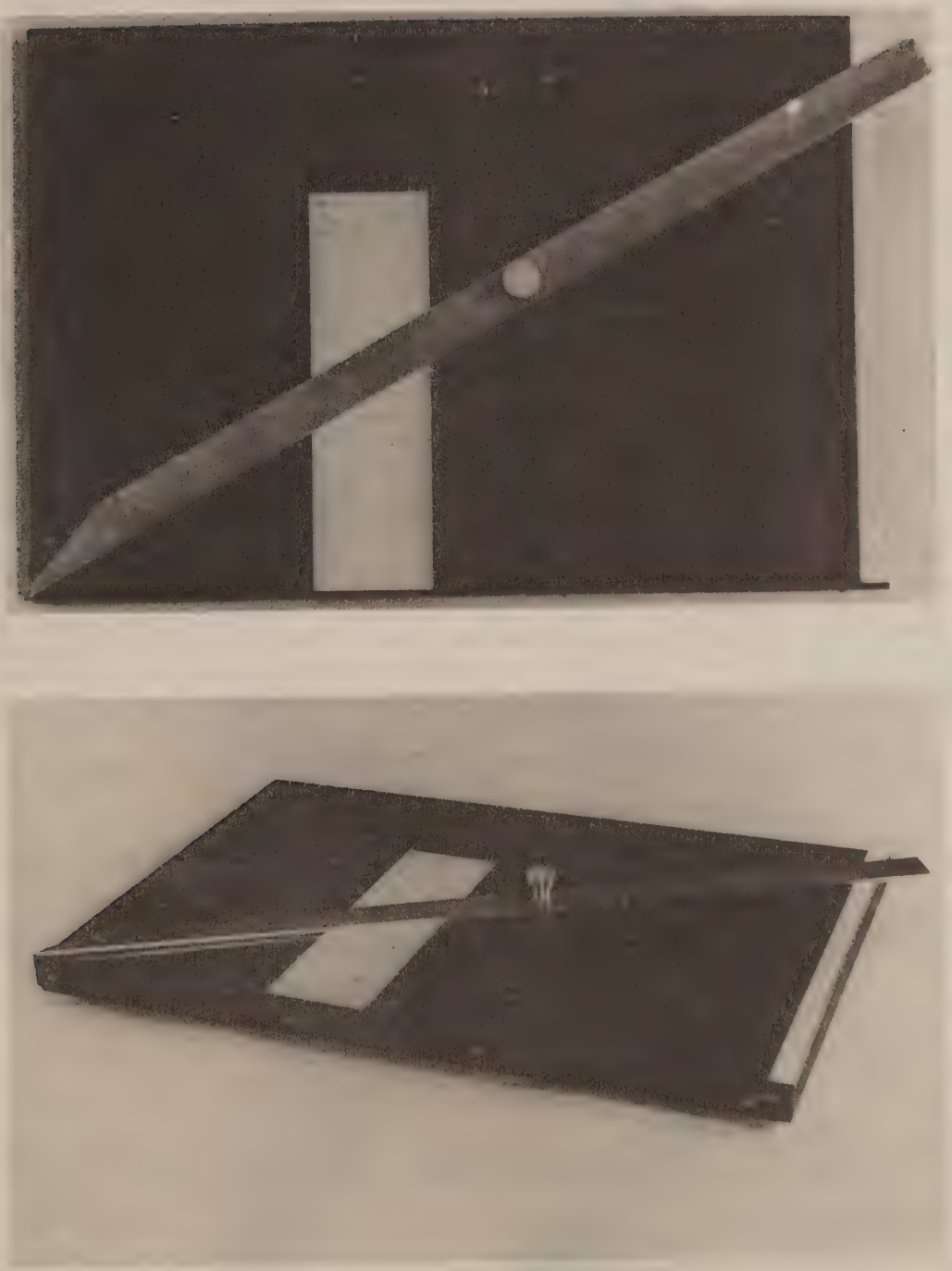


Figure 42 A proportioning board

It is much less easy to back-calculate lengths from otoliths than from scales. In whole otoliths the edges of the zones are rarely well defined and in sectioned otoliths the same difficulty exists. In addition there is the difficulty of sectioning the otolith accurately across the middle of its nucleus. As already described in section 5.5.1.4, the relative size of the zones depends upon the point at which the section is made. Small differences in the point at which the section is made may be perfectly acceptable for age determination, but can result in a considerable difference in the size of the zones that are visible for measurement. A series of transverse sections taken through the nucleus of the same otolith will show considerable differences in both the shape of the otolith and the size of the rings (Figure 43). If measurements are made on otoliths they are taken with a calibrated graticule fitted in the eyepiece of the microscope. Projection techniques cannot be used because the intensity of illuminations is too low.

6.1.2 Linear allometric growth

Since the growth of scales and other hard parts is rarely isometric, the direct proportion formula for back-calculating body lengths is not strictly justified. Scales and many bones do not form in the larva until the body reaches an appreciable size and may grow subsequently at rates different from body length. Fishery investigators who worked on the assumption of isometric growth soon found differences between size estimated from hard parts and the size of young fish actually caught. The most common result is the tendency for the estimated length of a fish of any given previous age to be smaller for older fish than for younger ones. This was termed Rosa Lee's phenomenon after the name of the scientist who first noticed this tendency. In fact, this tendency was primarily caused by allometric growth of scales and other hard parts. However, it may be noted that this phenomenon may also result from the effect of gear selection which is related to size rather than age of fish. Thus, in the catch of such a gear, there will be fast-growing young fish as well as slow-growing older fish. If the relation between the fish size and scale size is estimated from a sample taken from such a catch, then the estimated back-calculated size of fish at any given earlier age will be smaller than the true size at the same age (Jones, 1958; Ricker, 1975).

If linear allometric growth is assumed, the relation between l and r is given by:

$$l = a + br$$

where 'a' represents the body length at the time of scale formation and b represents the growth rate of r in relation to that of l.

If l_i is the body length at the formation of i^{th} ring on the scale, then based on the assumption of linear allometric growth, the formula for back calculation of body length l_i is given by:

$$l_i = a + br_i$$

$$= a + (l-a)\frac{r_i}{r}$$

The value of 'a' is usually determined by extrapolating the regression line represented by plotting the scale measurement against the body length.

6.1.3 Curvilinear relationship

There are sometimes small differences in the body proportions between small and large fish. In such cases, the relationship between scale and body length when plotted graphically is found to be curvilinear. The following general curvilinear relation may be assumed between l and r:

$$l = cr^b$$

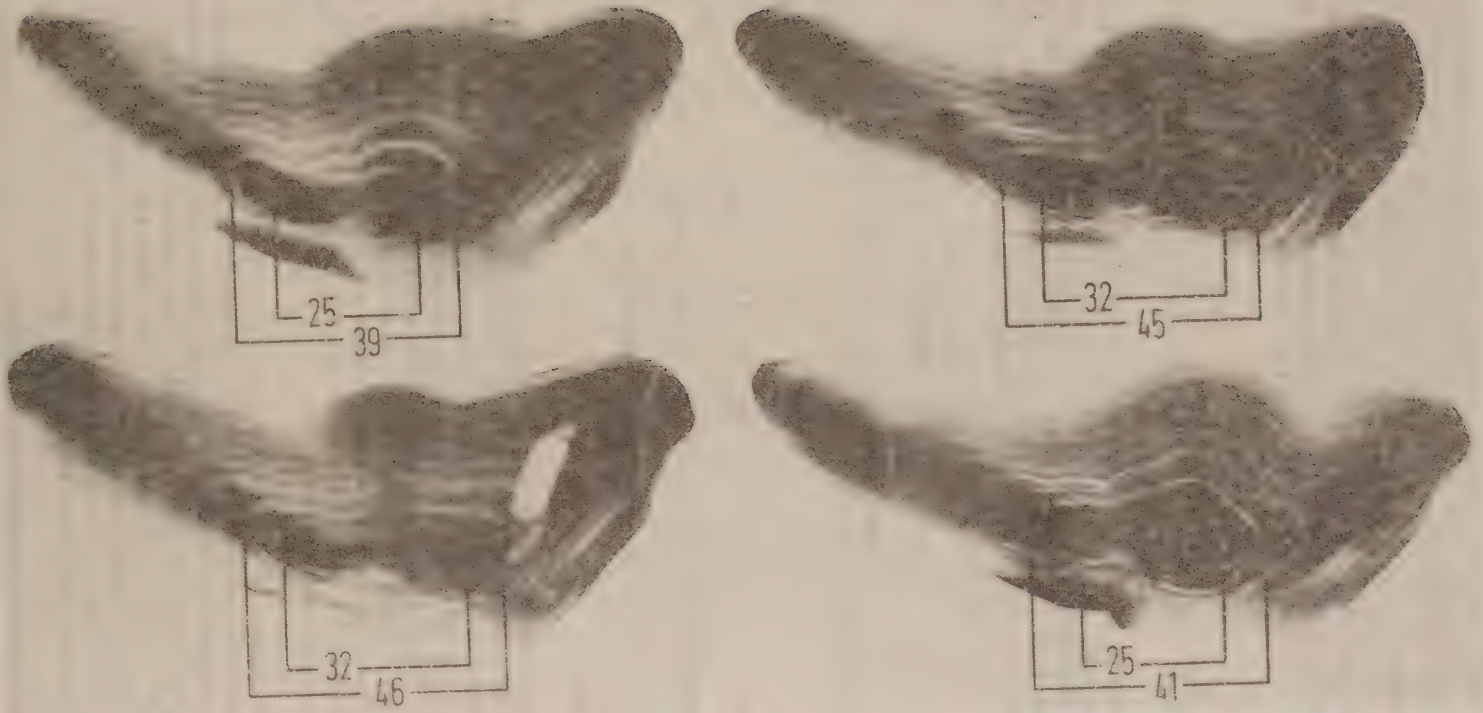


Figure 43 A series of transverse sections taken through the nucleus of the same otolith

By making logarithmic transformations, the above equation may be written as:

$$\log l = \log c + b \log r$$

or $$L = a + bR$$

which is a linear equation. Estimates of a and b and therefore c and b are obtained by fitting a regression line between logarithmic scale and logarithmic fish length measurements. Then L_i (and therefore l_i) are obtained from the relation:

$$L_i = \hat{a} + \hat{b}R_i$$

7. AGE COMPOSITION

The proportion of different age groups of fish in a catch or in the population is called its age composition. If the problem is to estimate the age composition of a single catch or haul of one species, this is simply done by determining the age of all the fish in the catch provided there is some structure which can be read. The table below shows the age composition of 200 fish of one species taken in a single trawl haul, where the age of every fish caught was read from scales.

Table 3

Age composition of a trawl catch

Age	II	III	IV	V	VI	Total
Numbers	24	102	45	20	9	200
% composition	12.0	51.0	22.5	10.0	4.5	

7.1 Age-Length Key

In the previous example, the age composition of a single small catch was obtained by directly reading the age of each individual fish from scales. Normally, the age composition of the total landings or of the whole population is required and it is not possible to directly age each fish in the landings or in the population. It would be perfectly feasible to age directly a random sample of fish drawn according to a suitable sampling scheme as in the case of sampling for length composition (section 3.8) and estimate the age composition of the total landings on the population. While this procedure may be adopted in certain special cases, usually the age composition of the total landings (or the population) is obtained by using an age-length key.

Because of variation in the growth pattern of individual fish, all fish of the same age are not of equal size or in other words all fish in a length group are not of the same age. The length composition of the commercial catch is usually estimated independently by sampling (section 3.8) and its age composition is derived by sampling for age in each length group. This is thus a case of stratified sampling, in which the strata are the length groups into which the entire length range of the fish is divided and sampling for age is done in each stratum. The question of the number of length groups or strata into which the length range of the fish landings is to be divided will be taken up in section 7.2.

Having decided on the length strata, a sample of fish is selected at random from each stratum. The ages of these fish are determined from scales or otoliths and the tabulated results used to make an age-length key. Table 4 is an age-length key of whiting caught off Scotland. The size interval of each length stratum is 2 cm and there are 15 strata. A

total sample of 377 whiting was selected and the numbers selected in each stratum are shown in the last column of the table. The ages of these fish were determined directly. It may be seen that 46 fish were aged 2 years old, 60 fish 3 years old and so on. Since the fish were selected by strata, the totals at the bottom of each age column do not represent the age composition of the catch. They must be combined with estimated numbers of fish in each length stratum derived from samples taken from estimations of the true length composition of landings to arrive at the age composition of the sampled population.

Table 4

Age-length key for whiting, trawl, Outer Hebrides, first quarter of 1968

Age	1	2	3	4	5	6	7	8	9	10	
year-class	1967	1966	1965	1964	1963	1962	1961	1960	1959	1958+	Total
length strata (cm)											
28-9		13	2								15
30-1		18	2	2							22
32-3		12	10	10		4					36
34-5		3	14	11		12					40
36-7			15	9		16					40
38-9			9	16	1	14					40
40-1			4	16		19		1			40
42-3			4	15	1	18	2				40
44-5				8		29					37
46-7				5		25	3				33
48-9				1		17	1				19
50-1				1	5	2					8
52-3					4						4
54-5					2	1					3
56-7											-

The second column of Table 5 gives the estimated number by length range of whiting landed in the first quarter of 1968. We now use the age-length key of Table 4 to estimate the age composition of total landings of whiting in the following manner. In Table 4 we know that in length stratum 28-29 cm, 13 out of 15 fish (i.e., 86.67%) were 2 years old and two fish (13.33%) were 3 years old. Assuming that the percentage of each age group in each length stratum is an unbiased estimate of the corresponding age group percentage in the total landings, we estimate that 86.67% of 8 100 fish in length stratum (28-29 cm), i.e., 7 020 fish are 2 years old and 13.33% of 8 100, i.e., 1 080 fish are 3 years old. The estimated value for other length groups is shown in Table 5. The sum of each column provides an estimate of the total number landed in each age group for all sizes.

Table 5

Whiting, Outer Hebrides, trawl, January-March 1969. Estimated numbers in total catch by 2 cm length groups and age (data from: Statistical News Letters No. 46, p. 142, 1968, changed and rounded off (ICES, 1970)

Length groups cm	Total numbers landed	Age						
		2	3	4	5	6	7	8
28-9	8 100	7 020	1 080					
30-1	13 147	10 757	1 195	1 195				
32-3	21 248	7 083	5 902	5 902		2 361		
34-5	39 068	2 930	13 674	10 743		11 721		
36-7	40 502		15 188	9 113		16 201		
38-9	48 540		10 921	19 416	1 214	16 989		
40-1	28 351		2 835	11 340		13 467		709
42-3	28 351		2 835	10 631	709	12 758	1 418	
44-5	15 204			3 287		11 917		
46-7	20 251			3 068		15 342	1 841	
48-9	8 100			426		7 248	426	
50-1	3 302				413	2 064	825	
52-3	1 246					1 246		
54-5	2 306					1 537	769	

Calculation becomes easier if a raising factor is used for each length group. This is obtained by dividing the total number landed by the total number aged for each length stratum. Thus for stratum (28-29 cm), the raising factor is 8 100 ÷ 15 = 540. Now, multiplying the number of fish of each age in this length stratum in the key by this raising factor, we get estimates of the number of fish in each age group, e.g., 540 x 13 = 7 020 and 540 x 2 = 1 080, etc.

If mean lengths at age are required for constructing growth curves, the age composition data (Table 5) should be used and not the data from the age-length key (Table 4).

It is important to point out that for estimation of the length composition of landings, length data are collected for samples of fish taken from many localities from all components of a fishery, but determinations of age tend to be made on the basis of a sample taken only from a few components of the fishery. It is pertinent to briefly discuss the likely biases that would result from estimation of age composition of commercial landings from the available length composition by using an age-length key prepared on the basis of a sample taken from only one component of the fishery.

(a) If the length sampling is unbiased, then bias can only be introduced in the key, if for a particular size group, fishes of certain ages are more likely to appear in the age sample than others. This is unlikely, since even a non-random selection of fish within a size group can only be related to size and not age. It is hard to imagine any one able to distinguish between two fish of the same size, but of different ages and pick up a fish of a particular age. Bias can, however, arise if among the selected fish, some are rejected or not used for age determination, especially if they are likely to be older ones in the length group. This can easily happen if the scales or otoliths that are difficult to read (generally slower growing, older fish) are omitted. Thus in general, if all length groups present in the commercial landings are represented in the sample used to make the key, and if sampling in each length group is at random, there will not be any serious bias in using such a key for estimation of age composition of all commercial landings of a given stock in a given year. The number of fish to be selected for each length group in the key sample will be discussed later.

(b) If a stock is being fished by several fleets, it is likely that the size composition of catch of each fleet will differ. This difference may be either due to differences in the selective properties of gear used by different fleets, or due to differences in fishing grounds exploited by different fleets. Gear selection is mainly related to size and not age, i.e., for a particular length group, a gear is unlikely to show any bias toward selection of fish of any particular age, but a particular gear may not catch all size groups represented in the catch of all the fleets and in this case, an age-length key based on samples from one particular fleet and applied to the length composition of catch of all fleets will produce highly biased estimates of age composition.

The frequency distribution of ages within a length group is likely to vary between different fishing grounds if growth rates of fishes are different on different fishing grounds. Hence, sampling from catches of one fleet for age may not truly represent the age composition of catch by all the fleets. This difference will be more pronounced where different fleets are exploiting different stocks and where fishes may have quite different growth rates, and as such different age structures within each length group. Similarly, as landings in different landing centres may come from catches obtained from different stocks, estimates of age composition of total landings for all centres by using a key made up from samples taken in one centre only may be highly biased.

(c) Frequency distribution of ages within a length group does not just depend on growth, but it is also affected by mortality and year-class strength, and since they almost certainly vary from year to year, an age-length key made from samples taken in one year, but used for estimation of age composition in another year will certainly yield biased results.

It is therefore important to emphasize that fish used in the sample for making an age-length key must be taken from the same stock during the same fishing season, and taken using gear having the same selective properties as that used in length composition samples. An age-length key made by sampling only a segment of the commercial fisheries cannot be used for length composition analysis of the whole fishery, unless it covers the same stock, and the whole size range available. Similarly, an age-length key cannot be applied to length composition of any year except the one from which it was derived, unless the year-classes represented each have the same initial abundance and have been subjected to the same fishing experience (i.e., the same mortality rate).

It is, therefore, important to note that samples used for making an age-length key should ideally be drawn from all sections of fishery and combined to give a single age-length key which can be applied either to total landings of each length group to give the total age composition, or to each section separately to give separate age compositions.

7.2 Sample Size for Age-Length Key

It has already been stated in the previous section that for making an age-length key, the entire length range of commercial landings is divided into a number of length groups or length strata and from each length group a sample of fish is taken for age determination. Now, the question is:

(a) how many length groups (= strata) are required? and

(b) what should be the number of samples in each length stratum?

The criterion of stratification by length groups is the same as in any stratified sampling where in each stratum the variability in the variate to be measured is small. In stratification of length groups, the criterion is that length groups should be small enough so that there is no marked difference in age distribution in each stratum. Ideally, each length stratum consists of a single age group. It may be possible to adhere to this criterion for smaller sizes where the fish grow fast and uniformly, but will not be for longer sizes where there is usually an overlap of age distribution. In theory again, all

length groups need not be equal, but in practice it is convenient to have equal length groups. The range of each length stratum is determined by the growth rate of a species. For small fish, the strata will necessarily be smaller than for large fish. Usually, a maximum of 20 strata is considered sufficient over the full range of sizes possible.

The number of fish to be sampled in each length group depends on the variability of age distribution with a group, and also on the precision desired in the estimate. The precision is measured by the variance of the estimate.

The variance of the estimated number of fish N_i of age i in a particular length stratum is given by:

$$V(\hat{N}_i) = \hat{N}^2 \cdot \frac{1}{n} \cdot p_i(1-p_i) + p_i^2 V(\hat{N})$$

where $\hat{N}$ = estimated number of fish in the total landings
n = number of fish sampled for age
p_i = proportion of fish of age i in the age-length key
np_i = estimated number of fish of age i in the sample

The variance of $\hat{N}_i$ consists of two terms: the first term is due to estimation of proportion p_i of the i-age group in a given length group, and the second term is due to estimation of the number N of fish in the same length group in the landings. The first term is usually larger than the second. The precision of estimate N_i increases as the value of $V(N_i)$ decreases. Now, the second term is zero, if N is precisely known (since in this case $V(N) = 0$), and the value of the first term decreases, i.e., the precision increases, as sample size n increases. However, precision also increases with increasing p_i. If $p_i = 1$, i.e., all fish in a length group are of the same age, the first term is zero and the variance of N_i tends to zero if the number N of fish of that size and age in the landings is known.

Thus, the length groups in the age-length key should be sufficiently small so that as few age groups as possible appear in each length group. The young fish usually grow faster than the older ones and therefore only a few and often only one age group will appear in length groups of young fish. As the fish become larger, the number of age groups in length strata of these fish increases. Thus it is necessary to have larger samples for age determinations in the length strata of larger fish than for those of smaller fish, but since the abundance decreases as the fish size increases, it may not be possible to increase sample size for these length groups.

The optimum numbers sampled in each length group are likely to depart quite widely from the proportions likely to be obtained by random sampling from the landings as a whole. In commercial landings the majority of the fish are likely to be concentrated in the smaller length groups. The number of fish of the ages represented in these groups will therefore be known very precisely, while the estimates of the numbers of older fish will have considerable variance. For many purposes, it is desirable to estimate the numbers of important age groups with roughly equal precision. For instance, if mortality is being estimated as the ratio of 5-year old to 4-year old fish, it is little help if the estimate for 4-year old fish is very precise and that of 5-year old fish is of poor precision. A reasonable system of sampling should therefore be to take equal numbers for age analysis from each length group. Even then the younger ages are likely to be estimated more precisely.

7.3 Frequency or Age-Length Key

For slow growing fish, annual age-length keys are usually considered adequate but for fast-growing fish, age-length keys for shorter periods are necessary. This is particularly likely to apply to short-lived species including many tropical fish which show fast growth rates. Table 6 shows quarterly age-length keys for the smaller sizes of cod caught in the North Sea in 1960, in terms of numbers of fish of each age in the samples.

Table 6
Size frequency of North Sea cod caught in 1960, showing age composition of 5 10 cm size groups

Length group	30-39				40-49				50-59				60-69				70-79			
Quarter	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1 year old			12	56			1	23			1									
2 years old	36	26	36	8	62	51	73	50	15	41	54	63		2	13	43				
3 years old	1	4			4	1	3	2	18	9	6	2	19	21	25	17	4	28	27	30
4 years old									2				1	3		11	20	7	7	6
5 years old													1	1			9			
Total	37	30	48	64	66	52	77	75	35	50	61	65	21	27	38	71	33	35	34	36

So far as choice of seasonal groupings is concerned, the two smaller sizes in particular show very big changes during the year, so that a single grouping for the year is unsuitable. However, there is not much difference between successive quarters except for the smallest size, so that there is probably even less difference between months. Quarters, therefore, are a sufficiently fine sub-division of the year, and even two half-yearly age-length keys would be reasonably satisfactory. For the big fish, 70-79 cm, and still more for the bigger fish for which data are not given in the table, there is little seasonal change. For these, therefore, a single annual age-length key would be suitable. While it is quite in order to use age-length keys of different time intervals for different length groups, in practice it is convenient to use the same time intervals for all length groups.

8. USES OF AGE DATA

It has been stated in the introduction that age data are used in estimating parameters of growth curves and also in estimating mortality rates.

8.1 Growth Curves

Absolute growth is the average rate of increase of size in the survivors of the population at each age. It is usually plotted as the regression of length or average length on age for each age group. In general, the absolute growth curve in length exhibits an initial period of increasingly rapid increases in length followed by a decrease. There are many formulae which can be used to describe the growth pattern described above, but von Bertalanffy's (1938) growth equation is the most commonly used in population dynamics of fisheries. The size of fish l_t at any age t is given by:

$$l_t = L_\infty \left[1 - e^{-K(t-t_o)}\right]$$

where L_∞ is the maximum or rather asymptotic size, the fish would attain if it reached an infinite age, K is the growth constant and t_o is the theoretical age of the fish when its size is zero. It may be noted that von Bertalanffy's growth equation contains three parameters, namely L_∞, K and t_o and they can all be estimated from data on age and length using Walford's (1946) transformation of the Bertalanffy's equation as:

$$l_{t+1} = L_\infty (1 - e^{-K}) + e^{-K} l_t$$

where l_t and l_{t+1} are the size of the fish at ages t and t + 1 respectively and l_{t+1} is plotted against l_t. The slope of the fitted line is equal to -K, and the y-axis intercept is $L_\infty (1-e^{-K})$ from which L_∞ can be calculated. They asymptotic length L_∞ is also the length at which the fitted line cuts the 45° diagonal line from the origin. For estimating t_o, the Bertalanffy equation is rewritten as:

$$\log (L_\infty - l_t) = (\log L_\infty + Kt_o) - Kt$$

Fitting a regression of $\log (L_\infty - l_t)$ against t, we get the y-axis intercept as $\log L_\infty + Kt_o$, from which t_o can be estimated, since we now know the other two variables.

Example 8.1

The average lengths of ciscoes from Vermillion Lake, Minnesota at ages 2 to 11 are given in the first two columns of Table 7. A Walford line plotting l_{t+1} against l_t is shown in Figure 44. From the Walford graph we read as a first approximation L_∞ = 309 mm.

Table 7

Average weight and length of ciscoes from Vermillion Lake, Minnesota (Ricker, 1975)

Age	Length	Estimated	
(t)	(mm)	$(L_\infty - l_t)$	$\log_e (L_\infty - l_t)$
2	172	99	4.60
3	210	68	4.22
4	241	44	3.78
5	265	29	3.37
6	280	20	3.00
7	289	15	2.71
8	294	7	1.95
9	302	10	-
10	299	3	-
11	306		

Using L_∞ = 309 mm $(L_\infty - l_t)$ and $\log_e (L_\infty - l_t)$ are calculated in the third and fourth columns of the table.

The values $\log_e (L_\infty - l_t)$ are plotted against age in Figure 45. The slope of the natural log line is 0.66 and therefore K is −(antilog 0.66), i.e., 0.41. The y-axis intercept is 5.84. Therefore:

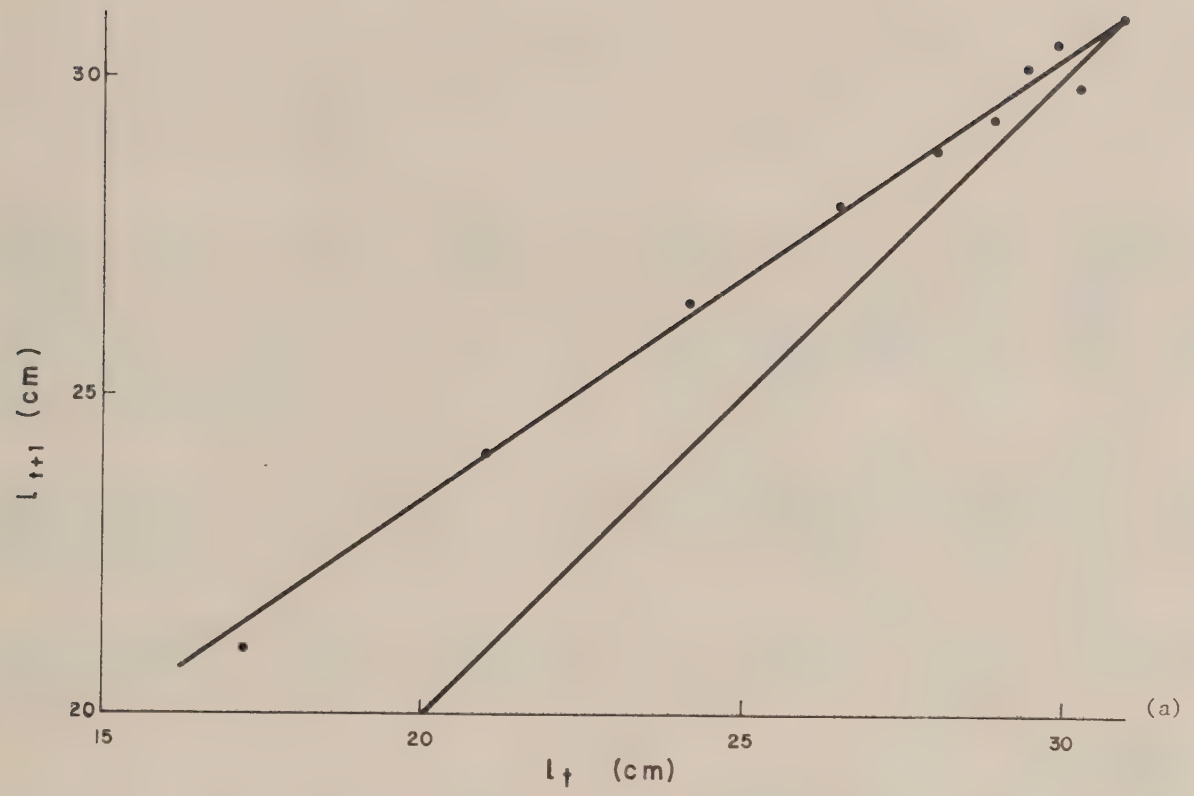
$$5.84 = \log_e L_\infty + Kt_o$$

$$\text{or} \quad t_o = \frac{5.84 - 5.74}{0.41} = 0.24$$

8.2 Estimation of Mortality

If N_1 and N_2 are the abundances of any group of fish at the beginning of two successive years, the annual survival rate s is given by:

$$s = \frac{N_2}{N_1}$$



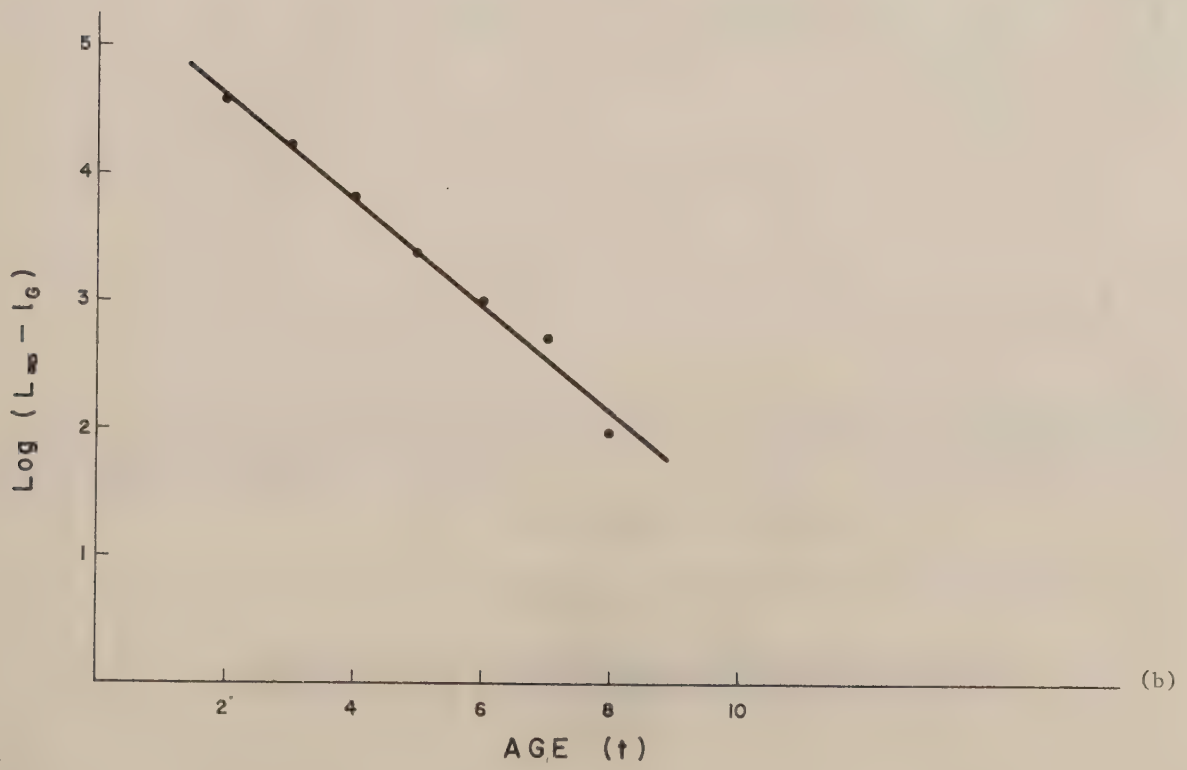


Figure 44 (a) Walford graph plotting l_{t+1} against l_t
(b) Log_e ($l_\infty - l_t$) plotted against t

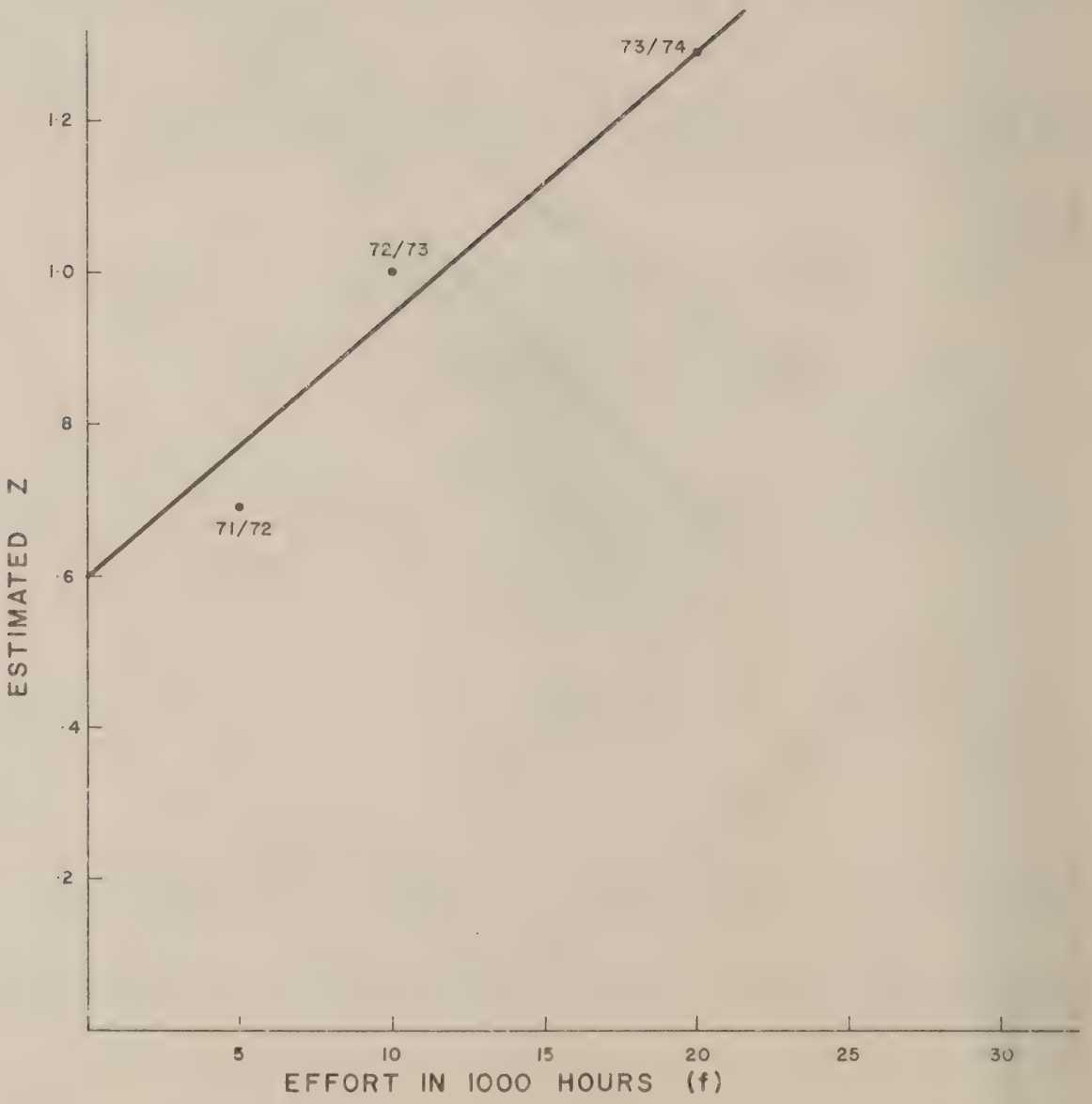


Figure 45 Estimation of natural mortality rate by fitting a regression line of Z values against f values.

The instantaneous total mortality rate Z is given by:

$$Z = - \log_e s = \log_e \frac{N_1}{N_2}$$

The formula for Z can be used even when true abundances are not known provided the relative abundances given by catches per unit effort are available. Usually, abundances or relative abundances will not be known at any particular times such as at the beginning of a year. The logarithm of the ratio of average abundances during two successive years will provide a good estimate of Z, if the mortality remains constant in the two successive years or the change in abundances during both years is small. Even if these conditions are not satisfied, a fair first approximation of the estimate of Z will be obtained from the formula by using values for mean abundances in successive years.

Thus for estimation of total mortality rate, we need age composition of fish catch in at least two successive years and also estimates of fishing effort during these years. Since for estimation of total mortality rate, we require at least relative abundances, the age composition of fish catches in successive years is first expressed in terms of standard measure of effort before the formula for Z is used.

A simple numerical example is given below to illustrate the method of estimation. Table 8 presents the estimated age composition of fish landings for four consecutive years along with the data of fishing effort during these years.

Table 8

Data of age composition and fishing effort

Age (years)	Number in 1 000				Effort in 1 000 h
	2	3	4	5	
1971	25	100	20	250	5
1972	140	100	100	20	10
1973	120	840	80	60	20
1974	120	270	390	30	30

The age composition data given for each year are converted to catch per unit effort for each age group by dividing the data of each year by the corresponding effort data and these converted data are presented in Table 9.

Table 9

Data of relative abundances (catch per unit effort) of various age groups

Year	Relative abundances in age groups			
	2	3	4	5
1971	5	20	4	50
1972	14	10	10	2
1973	6	42	4	3
1974	4	9	13	1

Now, logarithms of the ratio of relative abundances of two successive age groups chosen from consecutive years are calculated (e.g., $\log_e \frac{10}{5}$, $\log_e \frac{10}{20}$, $\log_e \frac{2}{4}$ between years 1971/72). The data are presented in Table 10.

Table 10

Calculated value of $\log_e \frac{N_{i+1}}{N_i}$

Year	Pairs of age groups			Mean
	2/3	3/4	4/5	
1971/72	-0.69	0.69	0.69	0.69
1972/73	-1.10	0.81	1.20	1.00
1973/74	-0.41	1.17	1.39	1.28

It will be seen that Z's estimated from relative abundances of 2 and 3 age groups are negative for all years. This means that the fish is not fully recruited to the fishery until age 3. Omitting these, the mean estimate of Z for each year is shown in the last column. It will be seen that Z increases as we proceed from 1971 to 1974 and this is to be expected since effort also increases during the period. If we plot the values of Z's estimates against effort (see Figure 45), we can fit a straight line through these points. This line cuts the y-axis at 0.6 which is then an estimate of natural mortality component M.

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Appendix I(a)

Example of the type of form used for recording measurements of many specimens of the same species

		CODE
MARKET		
NAME OF FISH		
DATE		
NAME OF VESSEL	=	
PORT LETTERS AND NUMBERS		*
MOTIVE POWER		
GEAR		
REGION		
RECTANGLE		
FISHING GROUND	=	*
NUMBER OF CATEGORIES SORTED		

	CATEGORY	STONES	CODE
TOTAL CATCH OF EACH CATEGORY OF THIS FISH, WHETHER SAMPLED OR NOT			
CATEGORIES NOT SAMPLED			
			—1

REMARKS

Appendix I(b)

Example of the type of form used for recording measurements of many specimens of the same species

CODE

CATEGORY VESSEL

Number of Stones Sampled: DATE FISH

..... of .....

• All fish measured; non discarded (*Delete as appropriate)

* 1 measured: ... discarded

| | | |

Appendix II

Standard form used by ICES for reporting length composition of annual fish landings by seasons and by fishing grounds

Netherlands. Number (in thousands) of North Sea whiting of different sizes landed at Dutch ports in 1962 specified by three-month periods

Length (cm)	Northern North Sea					Central North Sea					Southern North Sea				
	Jan.-March	Apr.-June	Jul.-Sept.	Oct.-Dec.	Total	Jan.-March	Apr.-June	Jul.-Sept.	Oct.-Dec.	Total	Jan.-March	Apr.-June	Jul.-Sept.	Oct.-Dec.	Total
20		12			12			5		5	42			1	43
21	1	6			7	3	9	9		21	2		4	22	28
22		11		2	13		11	13	1	25	112	6	8	49	175
23	2	23	7	9	41	5	20	40	1	66	41	3	28	119	191
24	6	40	19	20	85	19	53	49	1	122	176	46	52	210	484
25	29	99	32	42	202	28	87	89	4	208	237	109	92	260	698
26	114	160	60	73	407	58	165	205	18	446	484	186	145	366	1 181
27	252	227	102	93	675	75	217	362	36	690	721	375	256	427	1 779
28	506	309	139	168	1 122	79	242	459	47	827	1 101	603	328	396	2 428
29	864	343	139	185	1 531	54	213	486	60	813	895	723	377	498	2 493
30	1 011	314	170	230	1 725	42	233	533	62	870	1 055	734	550	402	2 741
31	965	262	182	285	1 694	42	191	479	35	747	634	601	368	328	1 931
32	883	258	177	251	1 569	23	166	425	46	660	409	421	317	263	1 410
33	730	188	124	249	1 291	18	87	326	38	469	343	393	258	194	1 188
34	456	152	85	220	913	8	70	216	42	336	131	278	256	127	792
35	354	117	57	199	727	3	55	164	25	247	176	203	183	80	642
36	217	69	36	154	476	3	31	111	24	169	89	141	133	50	413
37	148	55	29	171	403	4	8	118	13	143	50	79	84	50	263
38	77	35	12	129	253	2	7	71	10	90	13	59	52	27	151
39	78	29	11	103	221		7	34	5	46	10	47	35	18	110
40	39	9	15	84	147	1	10	6	10	27	4	28	30	10	72
41	28	13	3	42	86		6	15	3	24		17	9	5	31
42	17	10	4	39	70			10	1	11		7	12	5	24
43	8	3	4	17	32			3	2	5		5	6	2	13
44	10		7	17	34							1	3	1	5
45	4	1		9	14						2	1	2	3	8
46	5			6	11	1		1		2		5	1		6
47	5			4	9							1			1
48	2	1		1	4										
49	2			2	4										
50			1		1		1			1					
>50	1			2	3										
Total	6 815	2 746	1 415	2 806	13 782	468	1 889	4 229	484	7 070	6 727	5 072	3 589	3 913	19 301

Appendix III

A simple method of resolution of a polymodal distribution into normal components with Figure 46

1. Let y(x) be the observed frequency in the class with x as the mid-point and h the class interval. We plot:

$$D \log y = \log y\,(x + h) - \log y(x)$$

against x on ordinary graph paper and look for regions where the graph looks like a straight line with negative slope. Subject to certain conditions, the number of such regions is the number of components of a polymodal distribution.

2. If A_r is the angle the r^{th} line makes in the negative direction with the x-axis, and l_r is the x-intercept of the r^{th} line, then the mean and the standard deviation of the r^{th} component is given by:

$$m_r = l_r + \frac{h}{2} \tag{1}$$

and $$s_r^2 = (dh \cot A_r/b) - \frac{h^2}{12} \tag{2}$$

where b and d denote the relative scales of x and D log y respectively.

An estimate of the total frequency of the r^{th} component is given by:

$$\hat{N}_r = \frac{\Sigma y}{\Sigma P_r} \tag{3}$$

where the summation is taken over the region concerned and P_r is the distribution function of a standard normal deviate and is given by:

$$P_r(x) = P\{\frac{x + \frac{h}{2} - m_r}{s_r}\} - P\{\frac{x - \frac{h}{2} - m_r}{s_r}\} \tag{4}$$

Exercise

The data in the following table are taken from Tanaka (1962) and relate to frequency distribution of fork length of porgy caught by a pair trawl fishery in the East China Sea. Find the normal components of this distribution and the total frequencies of each component.

Solution

Obtain $\log_{10} y$ of the observed frequencies as in column 4 of the table and then obtain D $\log_{10} y$ as in column 5.

Now plot the log differences D $\log_{10} y$ against midpoint of the class on ordinary graph paper, the relative scales of x and D $\log_{10} y$ being 1 cm of x = 10 divisions and 0.1 of D $\log_{10} y$ = 20 divisions, so that b = 10 and d = 200 x $\log_{10} e$ = 200 x .43429 = 86.858 (the multiplication by $\log_{10} e$ is to express in natural logarithmic scale).

Table

Frequency distribution of fork length of porgies

Class range (cm)	Midpoint (x)	Observed frequency (y)	$\log_{10} y$	$D \log_{10} y$
(1)	(2)	(3)	(4)	(5)
9-10	9.5	509	2.707	0.643
10-11	10.5	2240	3.350	.019
11-12	11.5	2341	3.369	-.575
12-13	12.5	623	2.794	-.116
13-14	13.5	476	2.678	.412
14-15	14.5	1230	3.090	.068
15-16	15.5	1439	3.158	-.194
16-17	16.5	921	2.964	-.313
17-18	17.5	448	2.654	.058
18-19	18.5	512	2.709	.148
19-20	19.5	719	2.857	-.029
20-21	20.5	673	2.828	-.180
21-22	21.5	445	2.648	-.115
22-23	22.5	341	2.533	-.042
23-24	23.5	310	2.491	-.133
24-25	24.5	228	2.358	-.133
25-26	25.5	168	2.225	-.079
26-27	26.5	140	2.146	-.089
27-28	27.5	114	2.057	-.251
28-29	28.5	64	1.806	-.764
29-30	29.5	22	1.342	
Total		13963		

The graph shows four approximately straight lines with negative slope, indicating four distinct components. We have from the graph:

$l_1 = 10.53$ $l_2 = 14.78$ $l_3 = 19.36$ $l_5 = 26.12$

and $A_1 = 85.25^\circ$ $A_2 = 81.25^\circ$ $A_3 = 73.0^\circ$ $A_5 = 75.5^\circ$

Hence from equations (1) and (2) we get (since h = 1)

$m_1 = 11.03$ $m_2 = 15.28$ $m_3 = 19.86$ $m_5 = 26.62$

and $s_1 = 0.81$ $s_2 = 1.13$ $s_3 = 1.60$ $s_5 = 1.47$

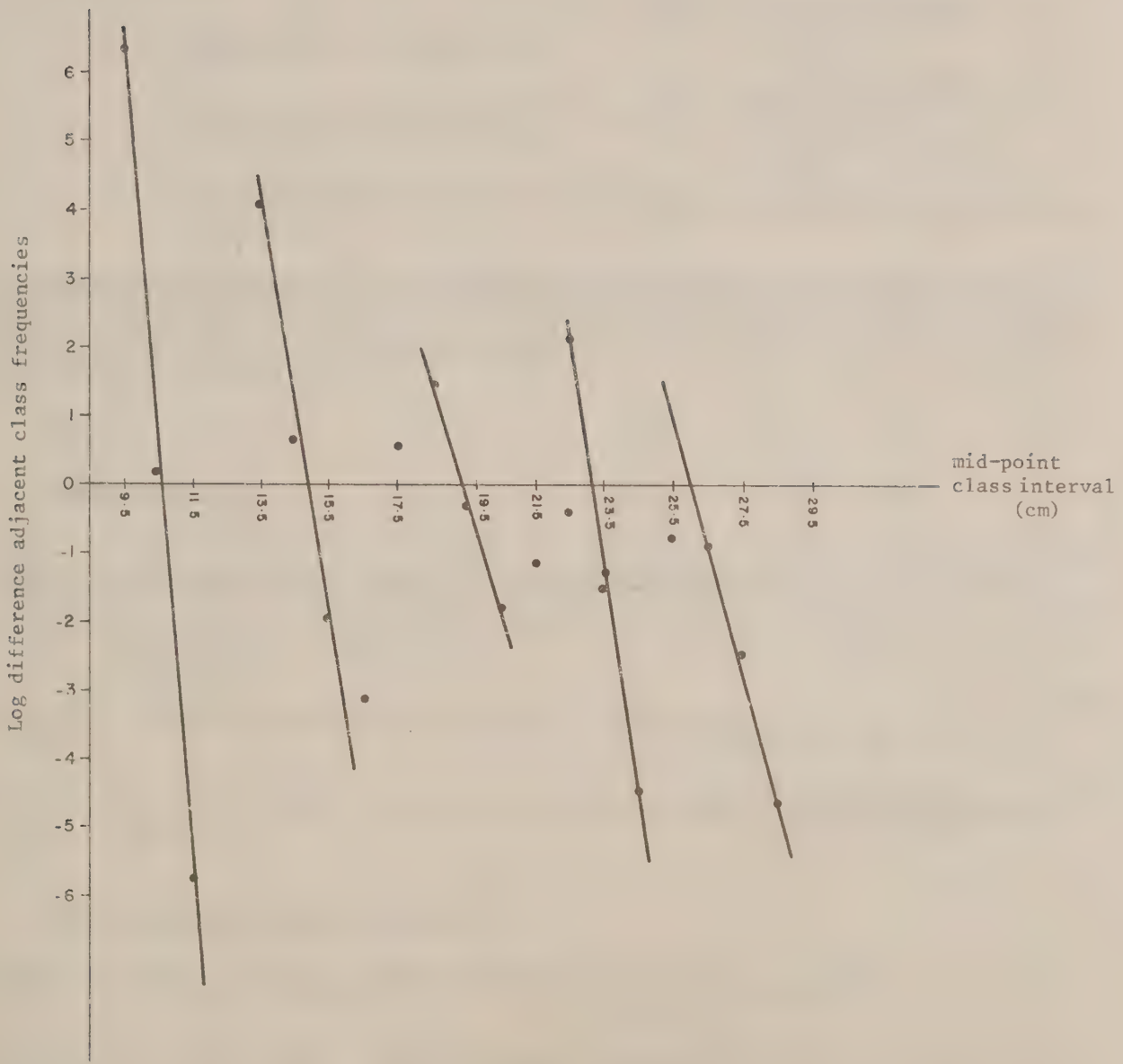

Figure 46 Graph of logarithmic differences of the class frequencies against the midpoint of the classes

The presence of a further component between the last two of the components, but substantially overlapped by them is also suggested. The parameters of this component cannot be estimated directly. We proceed as follows: From equation (3), we find:

$$\hat{N}_1 = \frac{y(10.5) + y(11.5)}{P_1(10.5) + P_1(11.5)} = 5\ 811$$

$$\hat{N}_2 = \frac{y(14.5) + y(15.5)}{P_2(14.5) + P_2(15.5)} = 4\ 381$$

$$\hat{N}_3 = \frac{y(19.5) + y(20.5)}{P_3(19.5) + P_3(20.5)} = 2\ 984$$

and $$\hat{N}_5 = \frac{y(26.5) + y(27.5)}{P_5(26.5) + P_5(27.5)} = 516$$

The contribution of the third and fifth components are now subtracted from the observed frequencies in the intermediate region and the calculations are shown below:

x	y	P_3	P_5	$Y_R = Y - N_3P_3 - N_5P_5$	$\text{Log}_{10}Y_R$	$D \log_{10}Y_R$
22.5	341	.00568	.00606	142	2.1523	.2169
23.5	310	.02002	.03045	234	2.3692	-.1517
24.5	228	.00417	.09788	165	2.2175	-.4251
25.5	168	.00060	.20139	62	1.7924	

The $D \log_{10}Y_R$'s are plotted against x and the new graph (crosses) shows an approximate straight region with negative slope. For this component we have:

$$l_4 = 23.12 \quad \text{and} \quad A_4 = 82.0^{\circ}$$

Hence,

$$m_4 = 23.62 \quad \text{and} \quad s_4 = 1.07$$

and $$N_4 = \frac{Y_R(23.5) + Y_R(24.5)}{P_4(23.5) + P_4(24.5)} = 639$$

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